Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

December 1960

Effects of Heated Discharges On A River

Protection For Feedwater Pumps

Consulting Engineering For Small Industrials

IN C-E PACKAGE BOILERS

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ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 32 number 6 **December 1960**

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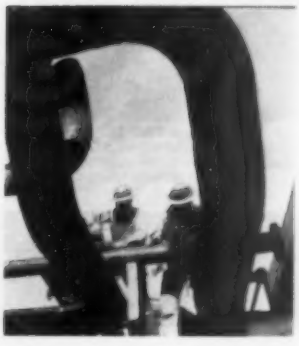
COVER PHOTO

Construction workers pause for that fleeting moment on a Fluor Corp. refinery installation



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REDISCOV

Coal operators on the C&O have done a revolutionary job of modernizing, in both mines and preparation plants to economically produce high quality coals. These investments prove coal is the fuel of the future.

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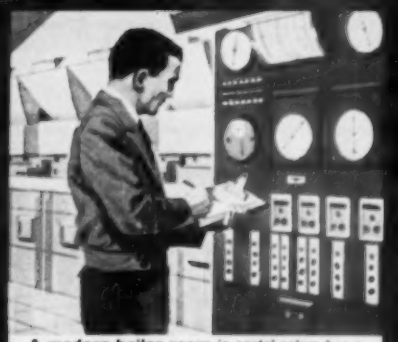

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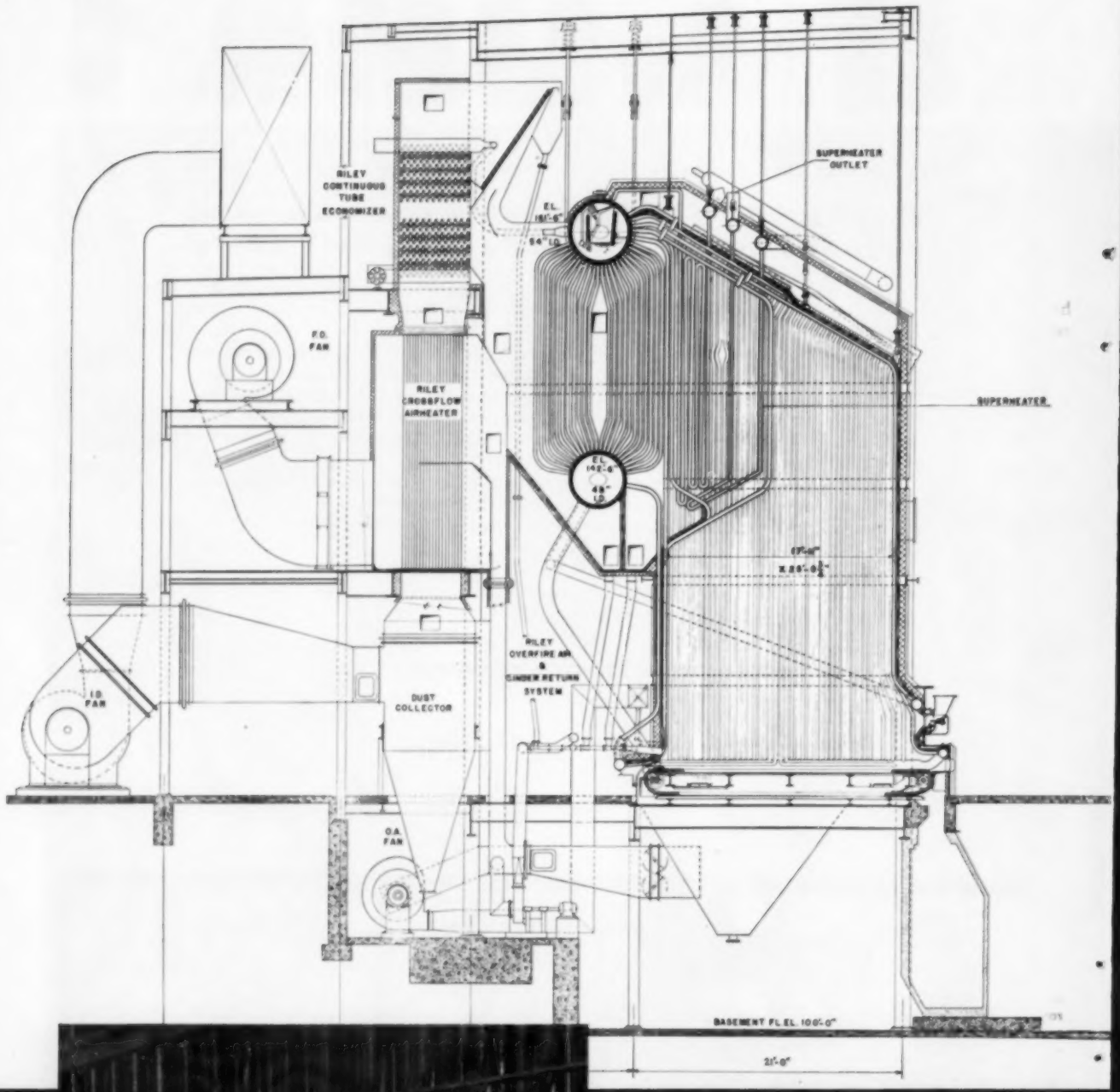

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Peak Capacity	275,000 lbs. steam per hour
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Republic ELECTRUNITE Boiler Tubes are accepted by boiler designers, engineers, and manufacturers. ELECTRUNITE is produced to meet ASTM specifications, the ASME Boiler and Pressure Code, and boiler insurance requirements.

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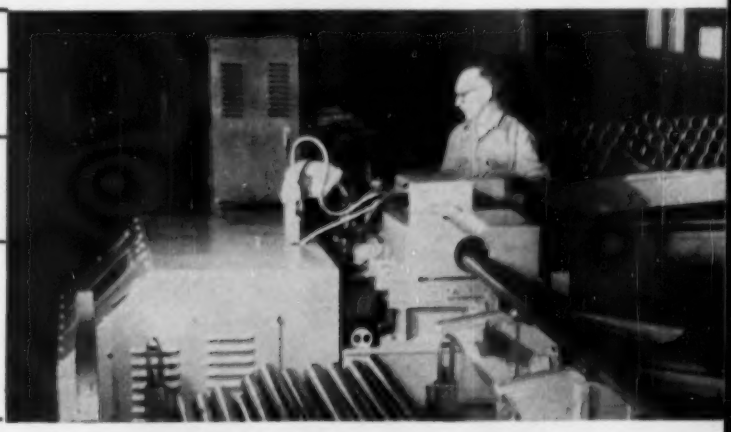
20	.006"	.0025 sq. inches
18	.006"	.003 sq. inches
16	12½% of wall	.003 sq. inches
14 and 13	12½% of wall	.004 sq. inches
12 and heavier	12½% of wall	.005 sq. inches

FARROWTEST detects and rejects not only tubing containing defects which completely penetrate the wall; but also tubing with defects equal to, or greater than, those shown in this table. For irregular defect shapes, a tube with defect area equal to or greater than shown above is rejectable. Where required, sensitivity of FARROWTEST equipment can be calibrated to reject defects of lesser specified area than shown in table, at extra cost.



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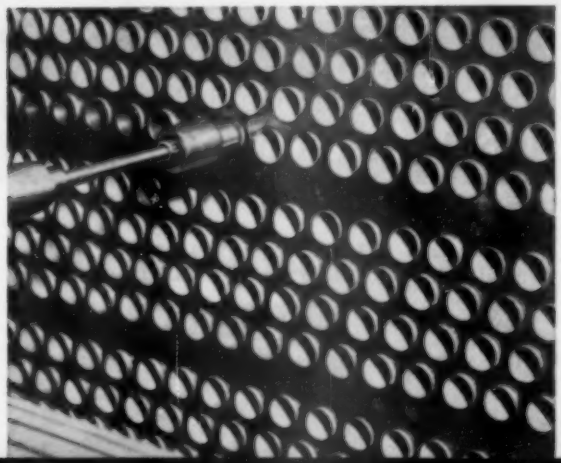

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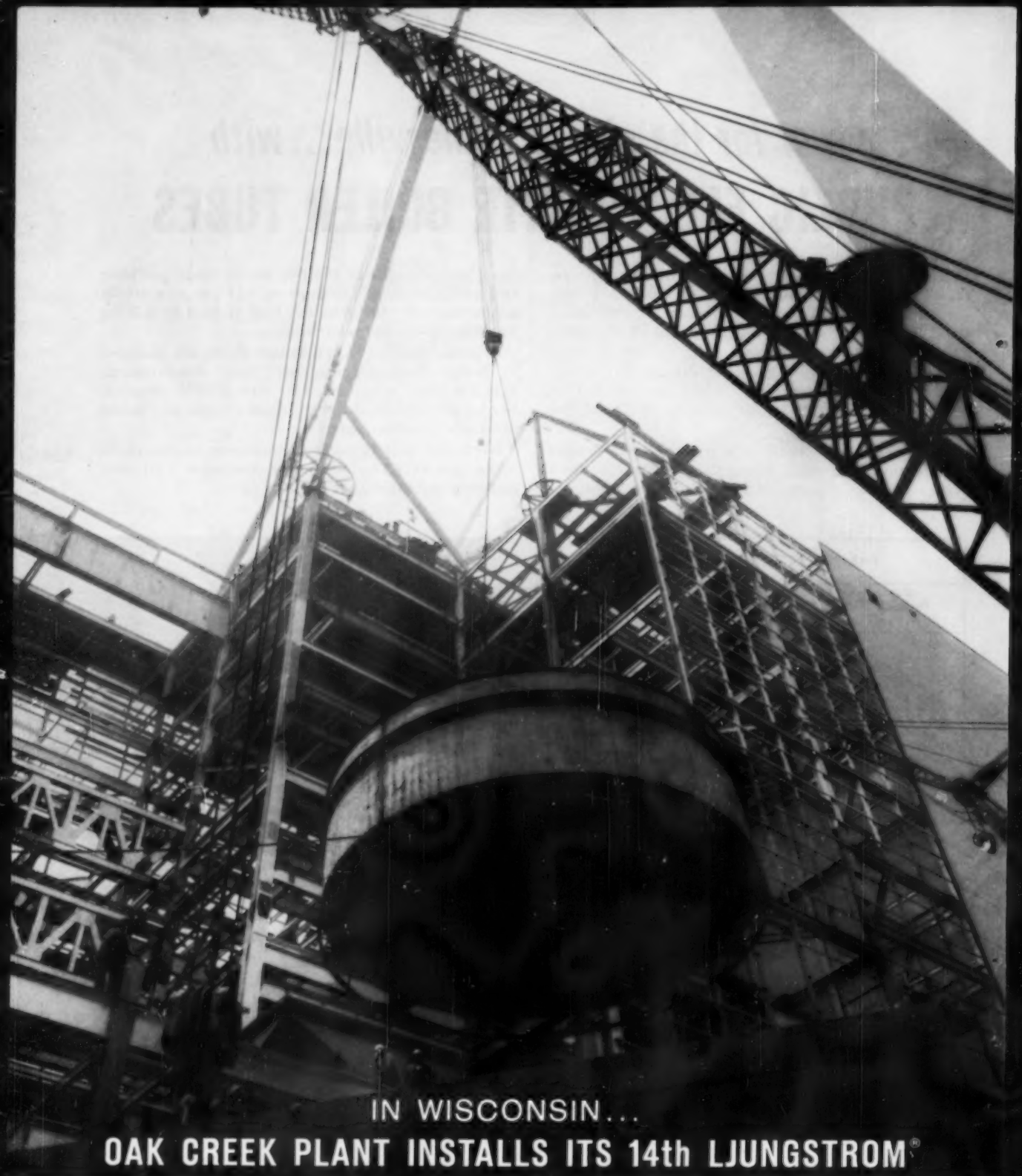

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OAK CREEK PLANT INSTALLS ITS 14th LJUNGSTROM®

Three new Ljungstrom Air Preheaters are being added to the eleven already in service at Wisconsin Electric Power Company's Oak Creek plant. These three 290-ton units will serve the 1,780,000 lb/hr boiler on Oak Creek's #6 unit. The three Ljungstroms, with a total heating surface of 795,300 sq ft, will reduce stack gas temperature from 550°F to about 270°F and preheat incoming combustion air from 190°F to about 510°F.

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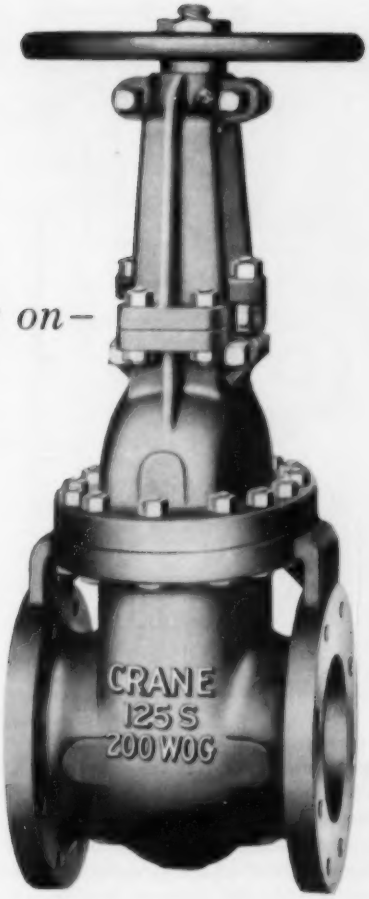

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Sizes 2" to 48".

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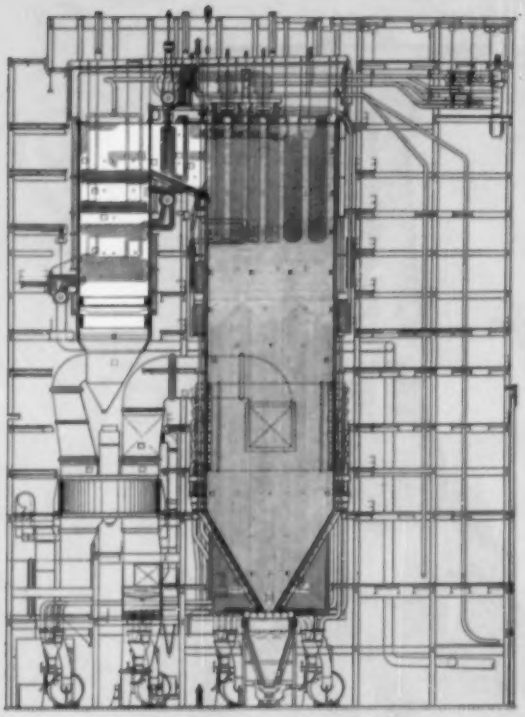
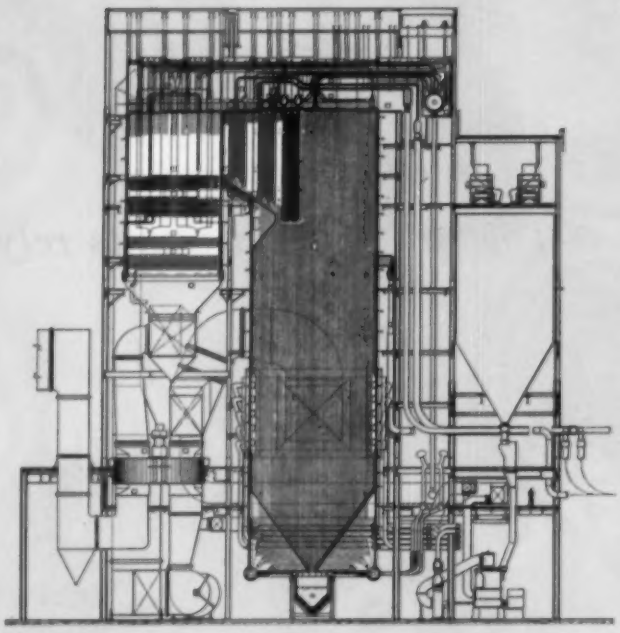


The unit pictured here represents the most advanced power plant cycle yet attempted. This boiler, a C-E Sulzer Monotube Steam Generator, is designed to deliver 1200 F steam at a pressure of 5000 psi to a 325-megawatt turbine-generator. The unit employs a double reheat cycle (1050 F—1050 F) and has a primary steam flow of 2,000,000 lb per hr. It went on the line in February, 1960.



This boiler, a C-E Controlled Circulation unit, serves the world's first 500-megawatt turbine-generator. Designed for a primary steam flow of 3,850,000 lb per hr, it delivers 1050 F steam (1000 F reheat) at 2450 psi. It was placed in service in 1960.

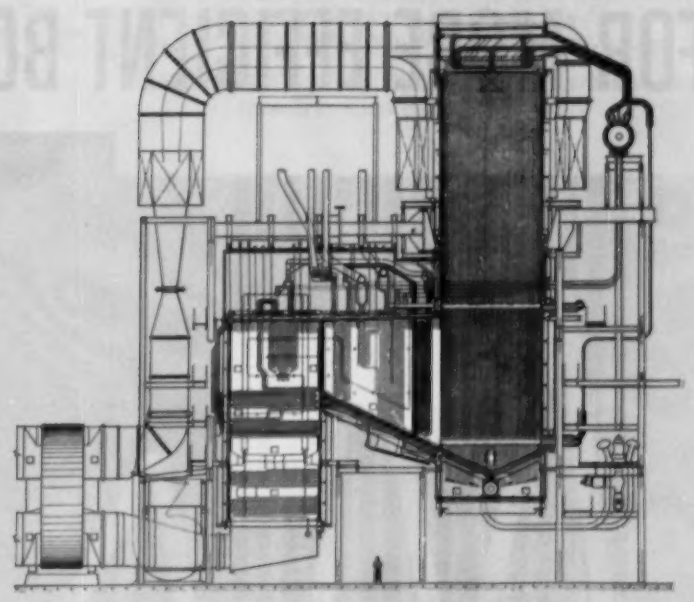
PROFILES

In 1950, a decade ago, Combustion installed some 40 utility boilers, representative of the complete range of power practice at that time. The average turbine capacity was 50 megawatts . . . the largest, 120 mw. All boilers were of natural circulation design, only two used reheat, only two had design pressures as high as 1800 psi. By contrasting these statistics with those of the boilers shown above, the length of the strides taken in the last ten years can be more fully appreciated.

A broader picture of current practice is revealed by the following data relative to 1960 C-E utility installations, which will serve nearly 4,000 mw of new capacity. Six of these boilers will power turbines of 225 mw and above, the largest serving a 500-mw turbine. All but two are designed for pressures in excess of 1800 psi . . . all employ reheat . . . about 60 per cent are of Controlled Circulation design. More than 70 per cent of the units serve turbines with capacities from 150 mw up. In fact, the average unit size is more than three times that of ten years ago, and the largest has

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS;

Shown here are three C-E boilers, each of which represents an advanced design concept. Their major points of difference concern capacities, cycles, configurations — considerations of major import in the industry's continuing effort to keep power costs down. As indicated by the picture captions, one unit (far left) is the world's highest pressure boiler and represents the most advanced and efficient cycle yet attempted in power plant practice. Another (left) is the world's largest boiler, serving the first 500-megawatt turbine-generator to go into service. Both of these units went "on the line" in 1960. Although different in design, both follow the same general pattern which has long been characteristic of large C-E utility boilers. The third boiler (right) represents a marked departure from this classic arrangement. Because of the flexibility of its C-E Controlled Circulation design, heating surface can be placed in almost any desired position. Thus, it becomes possible to effect sizable savings in structural steel, stairs, platforms, piping, earthquake-proofing, as well as in the boiler itself.



This new look, made possible by the flexibility inherent in C-E Controlled Circulation design, holds much promise of bringing new first-cost economies to power plant practice. This reheat boiler is designed to deliver 1050 F steam (1000 F reheat) at 2400 psi to a 300-megawatt turbine-generator. It has a primary steam flow of 2,305,000 lb per hr.

# of Power Progress

over four times the capacity of the biggest unit of 1950.

During the last decade, the vocabulary of the power plant has been enlarged with the addition of such words and phrases as "skin casing," "divided furnaces," "twin furnaces," "panel wall," "welded wall," "subcritical," "supercritical," "platens," "pressurization." They account, in large measure, for the fact that, while generating costs have risen considerably over the last ten years, the average net production cost per kw-hr is substantially less today than it was in 1950.

COMBUSTION ENGINEERING

C-298

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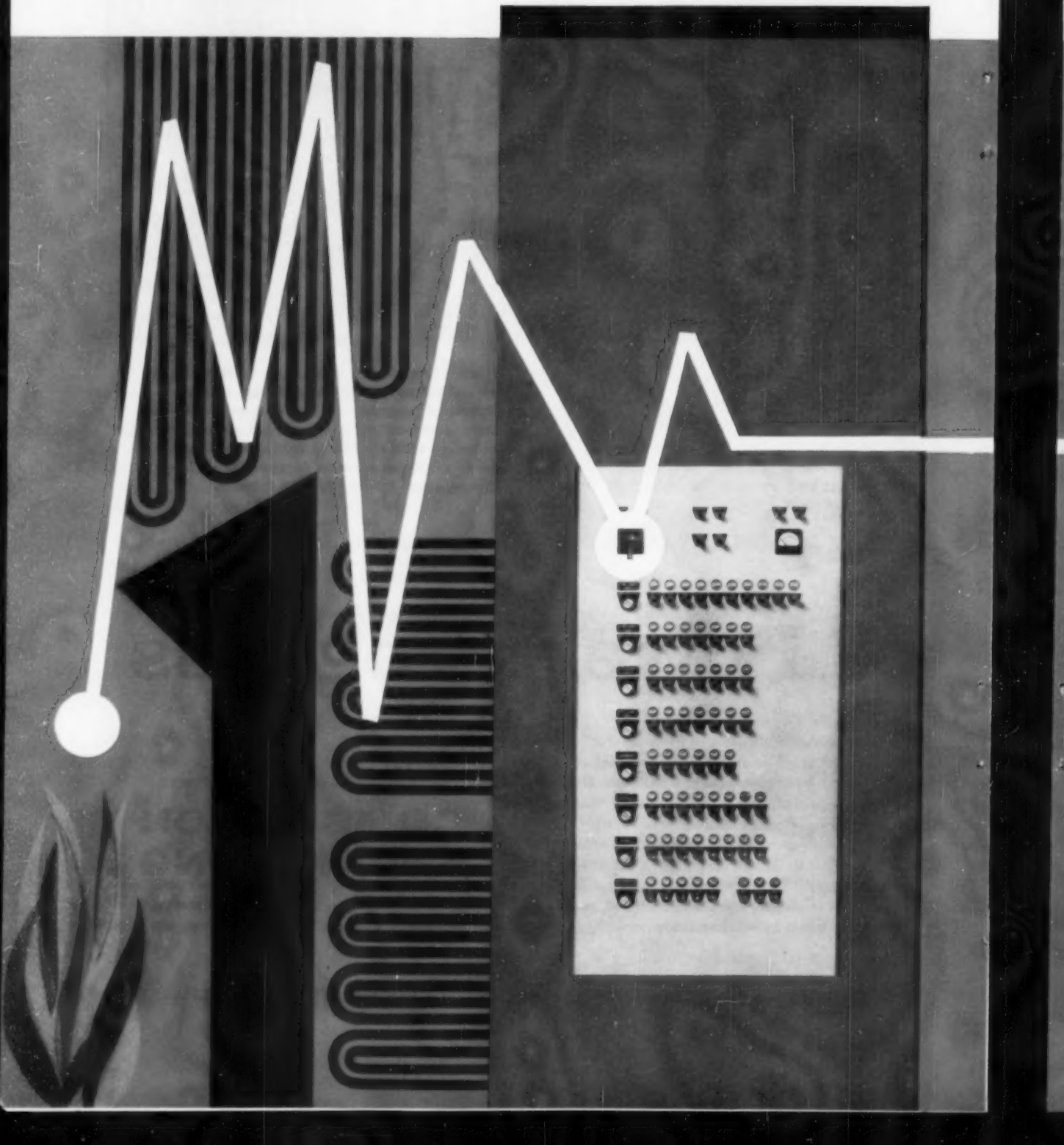

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Monitormatic is an automatic method of maintaining constant furnace cleanliness and heat absorption. It responds automatically to changing boiler conditions and eliminates indiscriminate, unnecessary or insufficient blowing. Savings are realized through optimum use of blowing medium, minimized soot blower maintenance, less compressor maintenance if air is used as blowing medium, and reduced operator time. It also automatically adjusts the cleaning system to fuel changes.

Monitormatic is readily and economically applicable to new or many existing Diamond Selectromatic Systems; is another example of why "Diamond Developed" means more economical power generation.

At your request, our Engineers will be pleased to evaluate the application of Monitormatic to your specific system. Call, write or wire for complete information.

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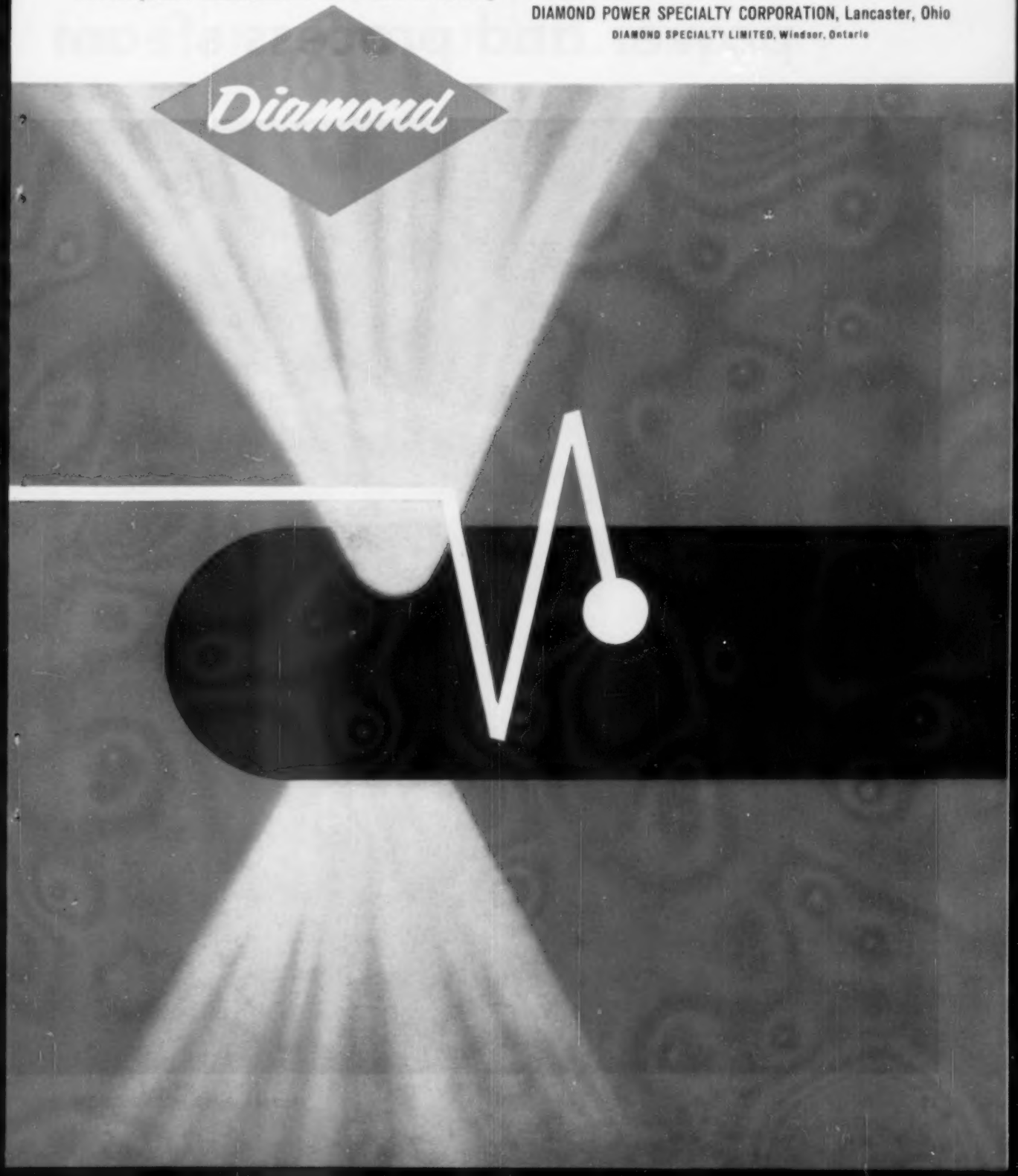

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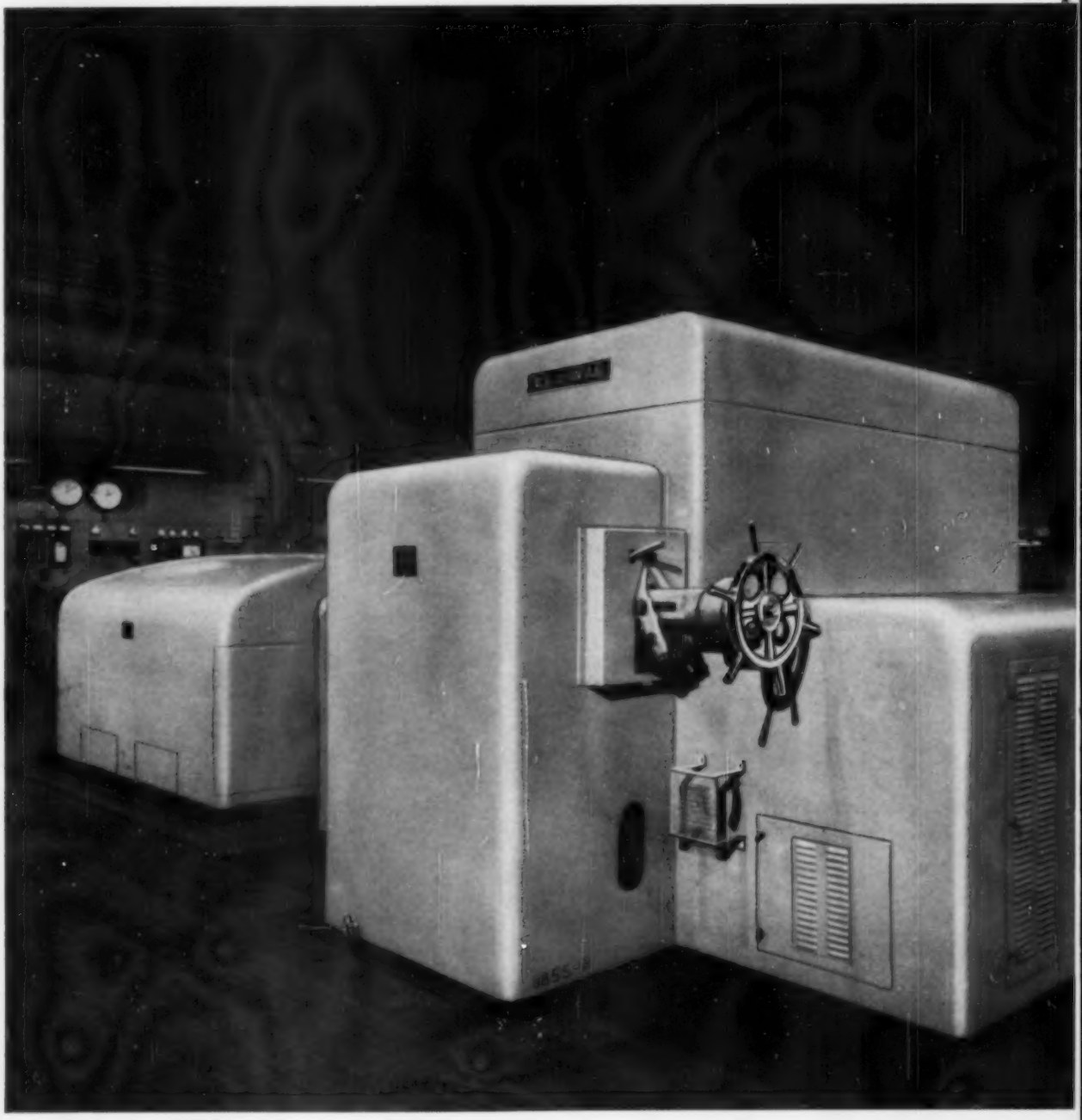

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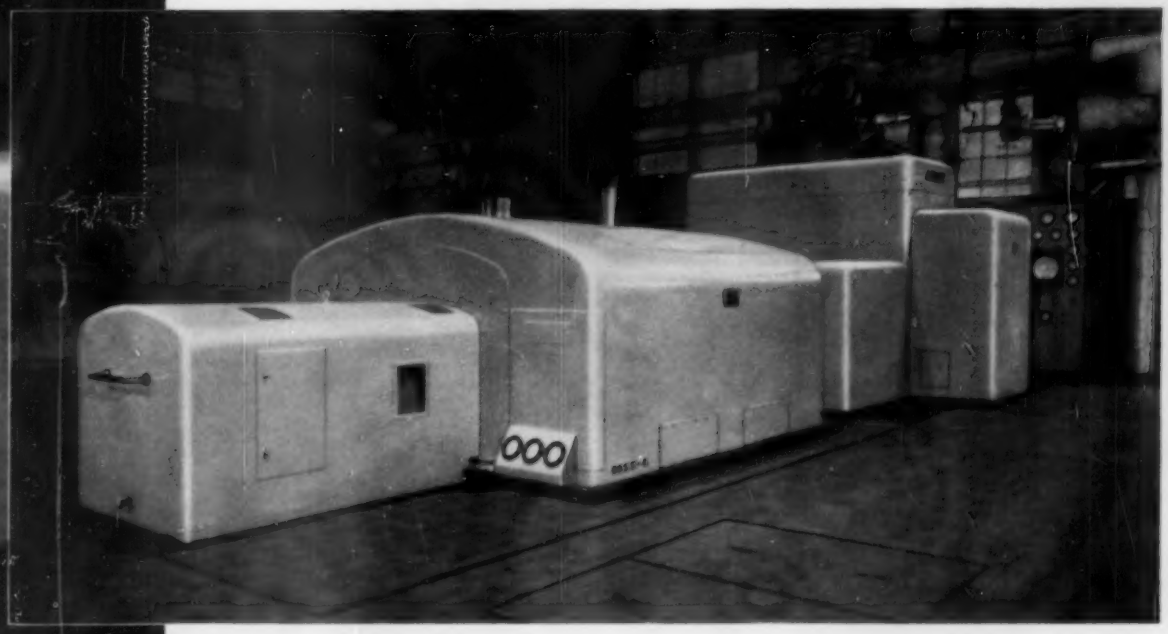
Sargent & Lundy, Consulting Engineers, handle project for new 9375 KW unit.

De Laval design engineers are specialists in meeting unusual requirements. For example, this unit at the Corn Products plant in Pekin, Illinois, is presently operating with 400 psig ISP at 580 F, with 6 stages to develop 5000 KW at a back pressure of 165 psig. Flexible De Laval design will enable this turbine to operate under new steam conditions with 11 stages for which space has been provided in the casing. When operating at its future steam conditions of 850 psig ISP, 700 F, the turbine will develop 9375 KW and will provide 275,000 pounds of steam per hour to the process at a pressure of 165 psig.

De Laval application engineers will gladly give you more information on steam turbines to suit your specific needs.



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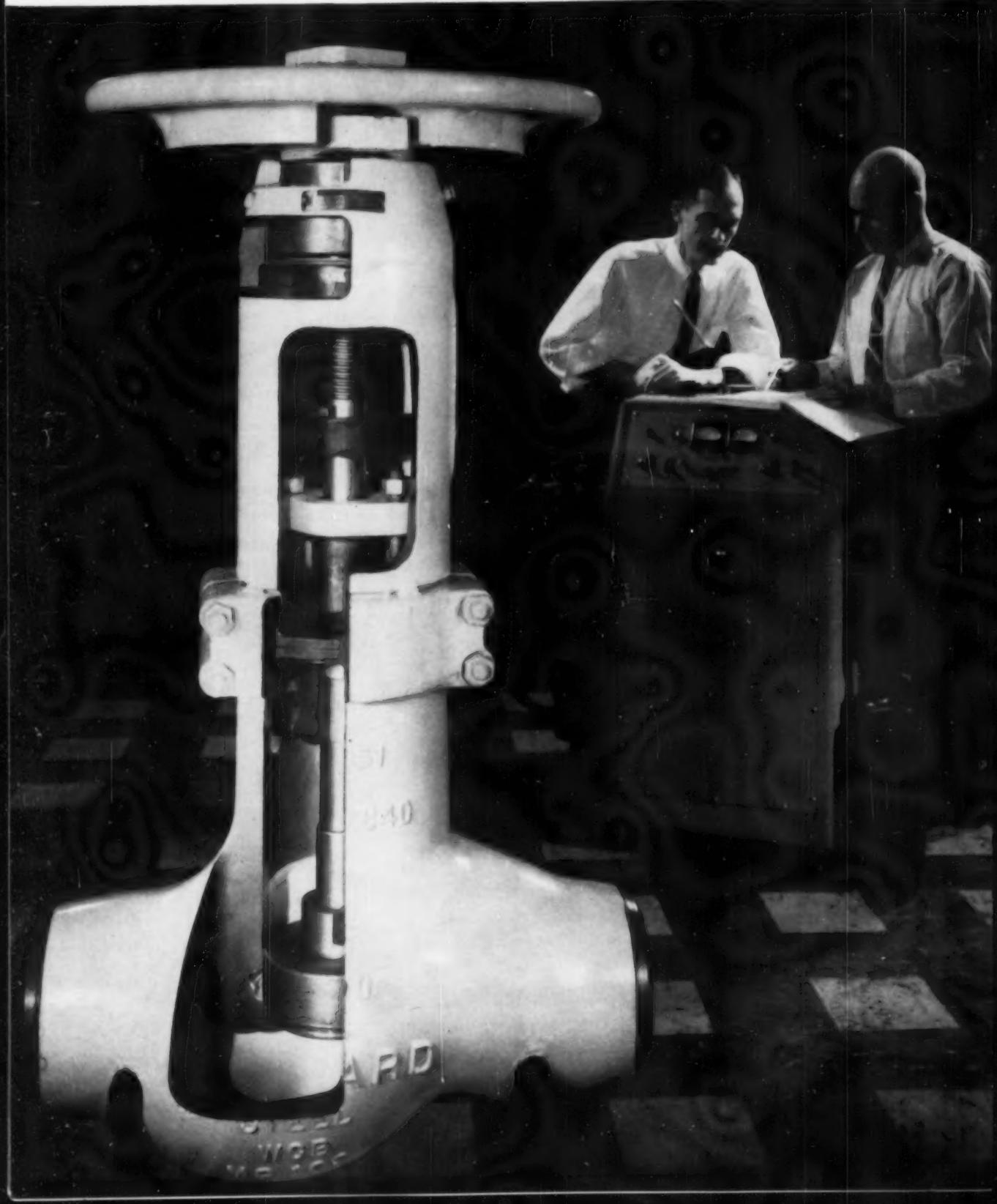
The Story of Edward Research



and the Pressure-Seal* Valve

The introduction, in 1945, of commercial steel valves with pressure-seal bonnet joint construction was a significant advance in the art of building large high-pressure steel valves. The new pressure-seal construction eliminated massive flanged bonnet joint connections and made it possible to seal the valves permanently at high temperature. These advantages were immediately apparent to users everywhere. But bonnet joint leakage problems developed on the new valves in service. And Edward engineers soon became convinced that the original 45° pressure-seal gasket design used by Edward and others required improvement. Here's the Edward pressure-seal redesign story:

INITIAL TESTING—Edward engineers began their studies on leak problems in 45° gasketed pressure-seal valves by determining under what conditions the valves were most likely to leak. It was discovered that when sealing areas were thoroughly degreased and tested with air, the pressure seal would leak at all pressures above 10 psi. In addition, minute imperfections in the sealing area of the valve body bore were preventing intimate gasket contact and contributing to leakage. Edward engineers found that a broader area of contact between gasket and bonnet and between gasket and body bore would also reduce leakage. Further investigation showed that a gasket plating material softer than the silver plating previously used would be helpful in achieving better contact in the sealing area.

To obtain more gasket sealing area, experiments were conducted on gaskets with angles from 45° down to 17°. Over a period of several months, tests were made with 25 different combinations of gasket and bonnet angles and various gasket plating materials. Assembled valves were tested for tightness with air pressures ranging from 10 psi to 2160 psi, and at temperatures up to 1000 F for extended periods. And tests on ease of valve disassembly (an important user consideration) were made with each gasket combination.

TEST CONCLUSIONS—At the end of their extensive testing program on the pressure-seal design, Edward engineers were able to draw these conclusions:

1. 45° gaskets, which showed no leak on water tests, leaked air at similar pressures.
2. No gasket of any design, either plain or with a plating of 100 Brinell or harder, would seal air when assembled unlubricated.
3. The best sealing under test resulted with a 25° gasket angle which was 1° more acute than the bonnet angle.
4. Gaskets of 25° angle actually tripled the sealing surface area.
5. A stainless inlay in the valve body bore sealing area substantially improved gasket-to-body contact and provided a corrosion-resistant surface.
6. Gaskets of 25° angle, plated properly with a malleable coating, gave perfect air or steam sealing at all temperatures, whether assembled dry or with a lubricant.

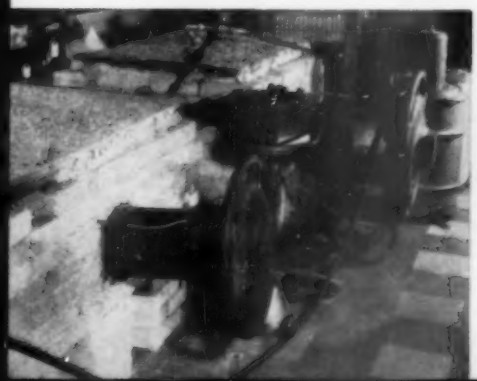
NEW VALVE DESIGN—As the result of their tests, Edward engineers designed the completely new pressure-seal valve with 25°-65° joint (see diagram below). This change in gasket angle, with an increase in sealing surface area, and the addition of a special corrosion-resistant malleable coating, brought an end to bonnet joint leakage in Edward pressure-seal valves. And, since 1953, thousands of Edward pressure-seal valves have been installed in a great variety of services *without a single case of failure reported to date.*

The story of Edward research and the pressure-seal valve is typical of the kind of research progress and product leadership you can expect from Edward Valves. Edward builds a complete line of forged and cast steel valves from ¼" to 18" for industrial, marine, petroleum and technological services. For more detailed information, contact your Edward Representative, or write Edward Valves, Inc., 1206 West 145th Street, East Chicago, Indiana. Subsidiary of Rockwell Manufacturing Company. Represented in Canada by Lytle Engineering Specialties, Ltd., 438 St. Peter Street, Montreal.

*Patented

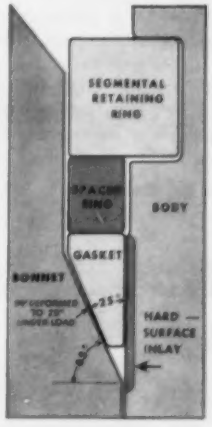
EDWARD STEEL VALVES
another fine product by
ROCKWELL

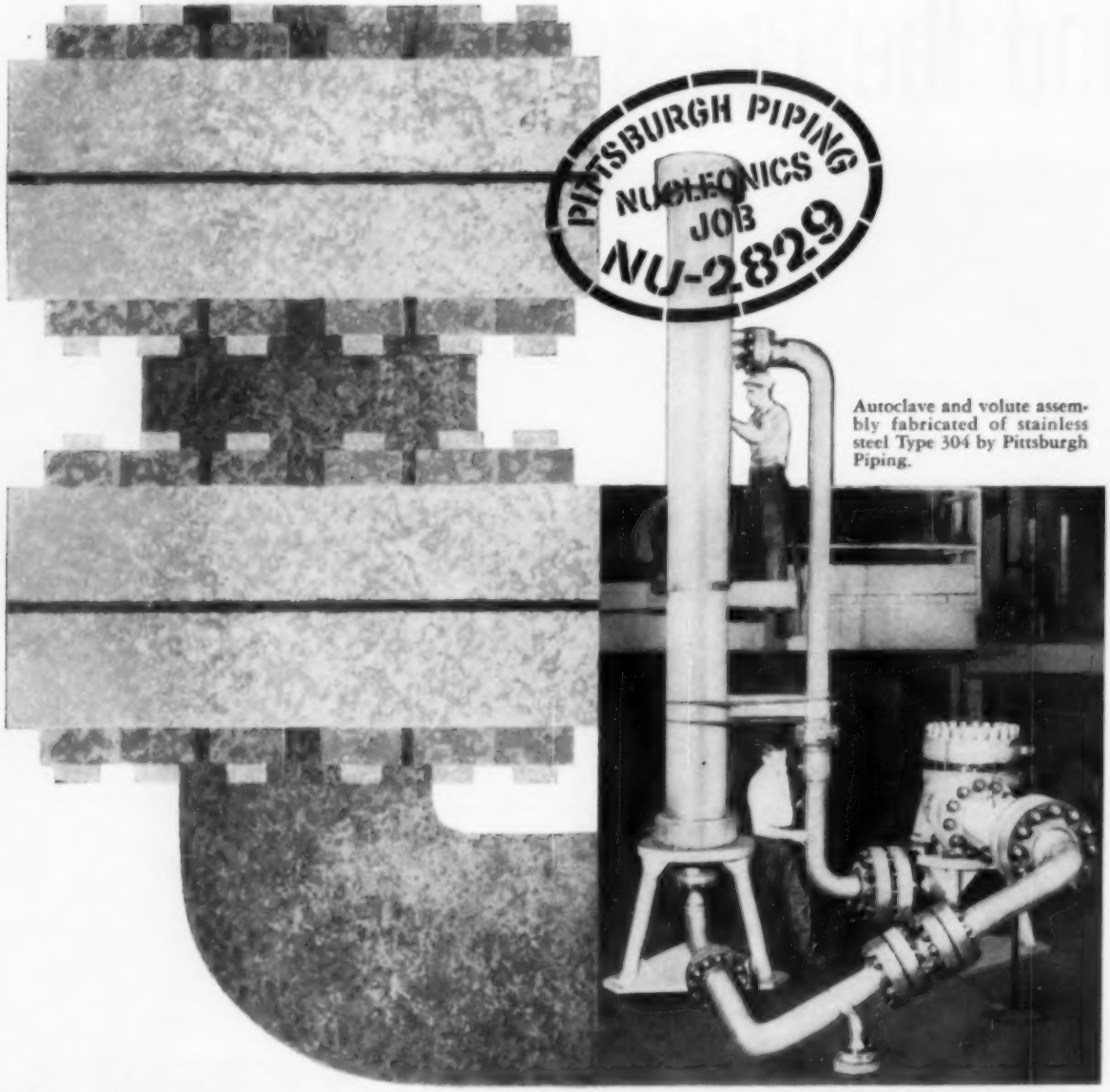
P. J. DUKES, product development engineer, and D. MacGregor, works manager, are shown with helium leak detector used in testing pressure-seal valve joints.



SPECIAL GAS-FIRED FURNACES were used in temperature testing of new pressure-seal valve design. Furnaces heated valves up to 900 F for 24 hour periods. Pressure was maintained with hydro-pneumatic pumps.

NEW 25° GASKET DESIGN





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Stainless steel autoclave and volute

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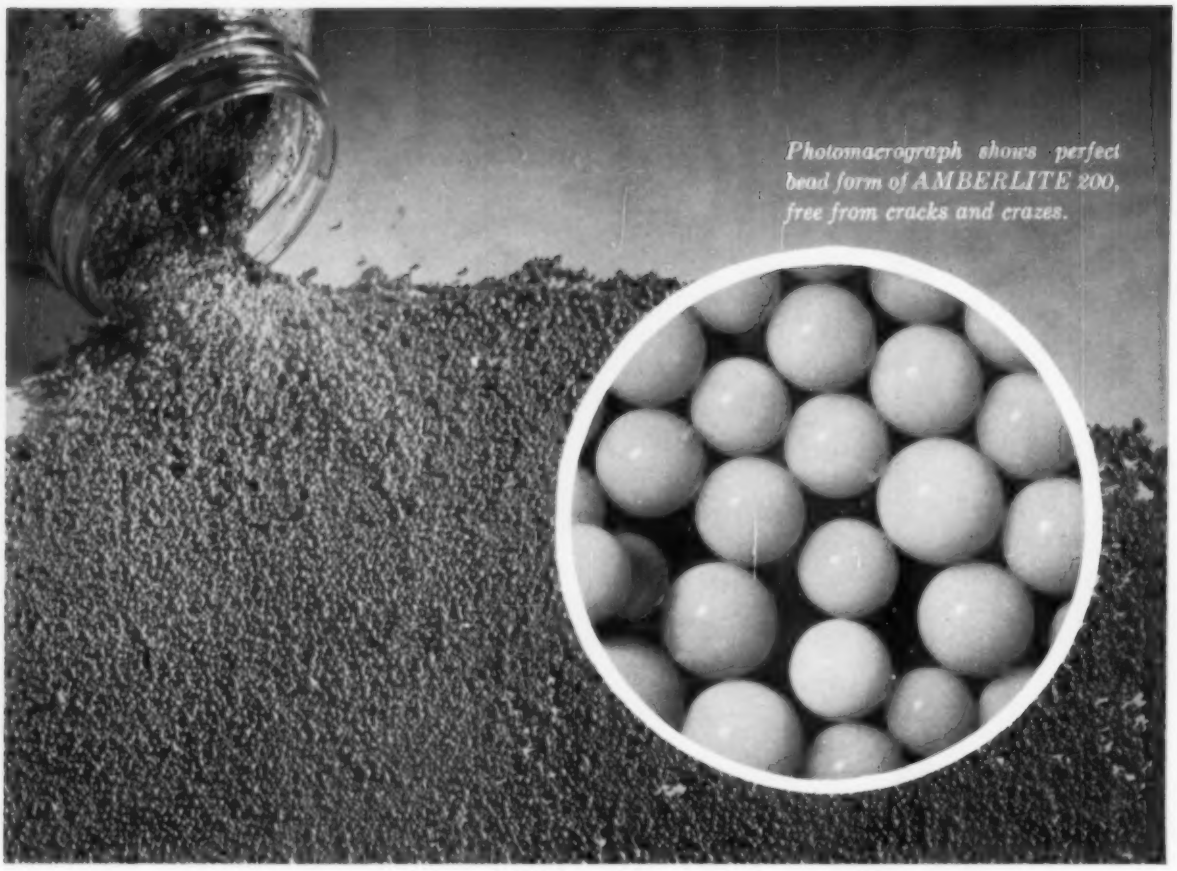

Photomacrograph shows perfect bead form of AMBERLITE 200, free from cracks and crazes.

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These are some of the outstanding features of AMBERLITE 200 . . . *high resistance to oxidation*, especially in water containing chlorine, oxygen and metals such as iron, copper and manganese; *perfect bead form*, free of cracks and crazes; *high attrition resistance; stability over the entire pH range; insolubility in all common solvents.*

In water treatment in either hydrogen or sodium cycle operation, the exceptional bead characteristics of AMBERLITE 200 make possible more rapid and complete bed classification, low losses from mechanical attrition, and greater freedom from bead fracture caused by thermal and osmotic shock. For example, 2000 regeneration-exhaustion cycles using saturated brine and calcium chloride showed no measurable resin breakdown, whereas conventional cation exchange resins showed failure of from 20 to 75 percent.

Write for full information and samples on this radically new AMBERLITE resin.

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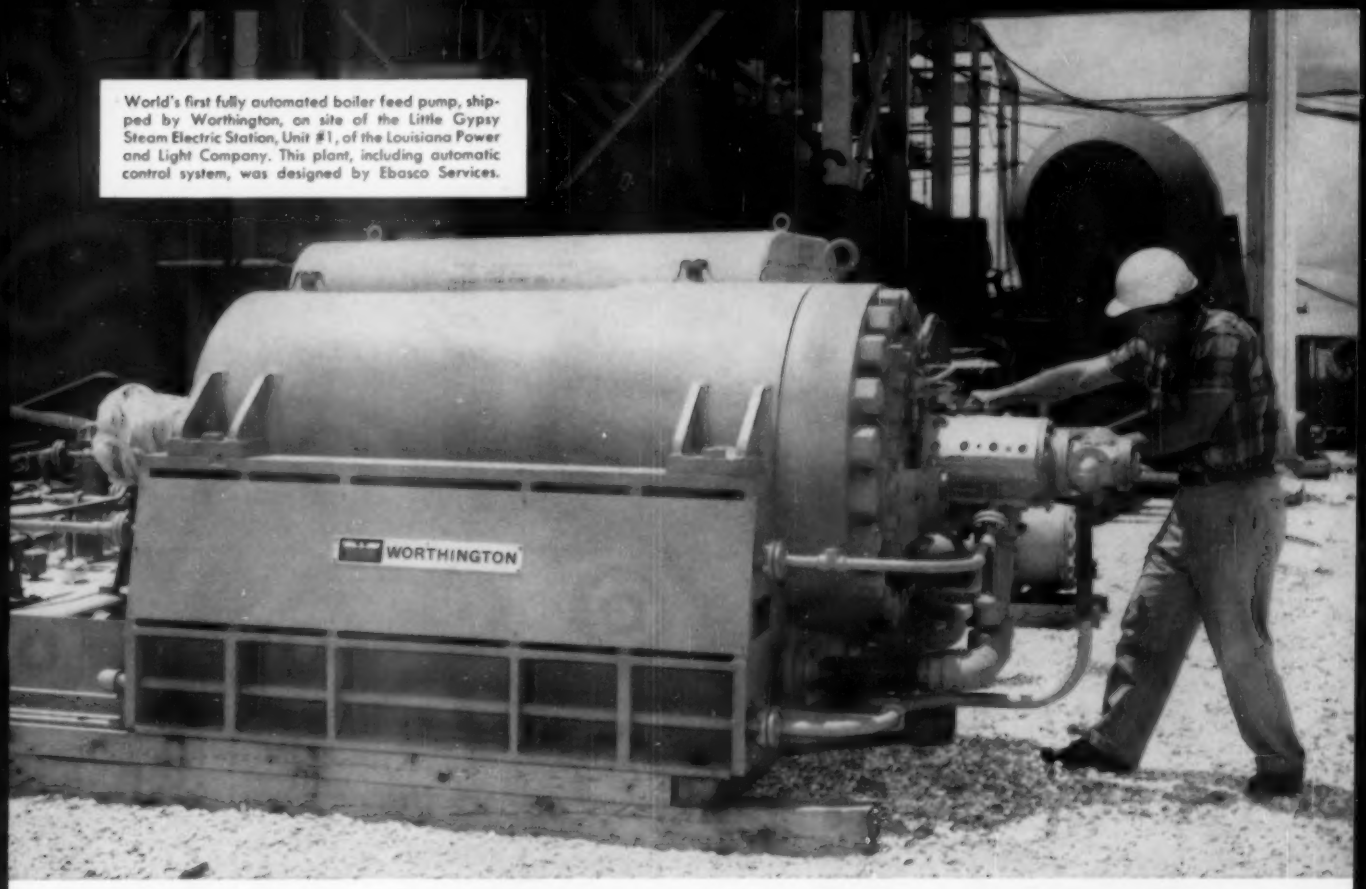
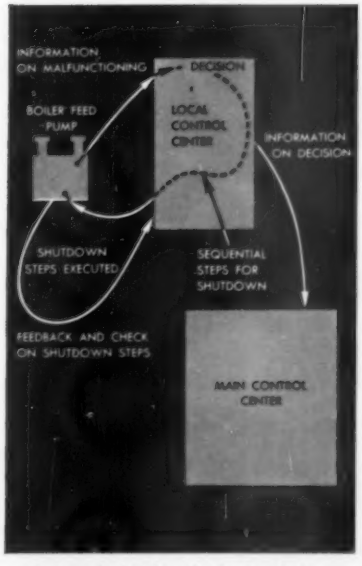


World's first fully automated boiler feed pump, shipped by Worthington, on site of the Little Gypsy Steam Electric Station, Unit #1, of the Louisiana Power and Light Company. This plant, including automatic control system, was designed by Ebasco Services.

WORTHINGTON DELIVERS THE WORLD'S FIRST FULLY AUTOMATED BOILER FEED PUMP

Should yours be next?



Automatic decisions for load variation: routine or emergency shut-down can be locally or remotely instrumented.

Frankly, we don't know. We do know, however, that we've shipped the first high-pressure boiler feed pump for a fully automated installation. Thus the "full automation" question looms bigger with each new plant.

What do we mean by "full automation," when important components have been automatically controlled for many years? We mean the use of improved equipment and instrument design and control techniques—plus modern data processing systems—in such a way that the power plant will operate continuously at optimum efficiency under varying loads, starting and stopping units as required with maximum equipment protection.

Now, is it your turn to install fully automated boiler feed pumps? Or other power plant components? That is, of course, a matter for you and your engineers to decide. But regardless of the degree of automation for which you design, we are sure that we can help you in studying the needs for instrumentation and control of the Fluid Handling Group.

Remember, we've many years in designing and building condensers and auxiliaries, generators, boiler feed pumps, compressors, turbines and control equipment. We call it "System-Wise Experience" . . . and have prepared an Automation File on Boiler Feed Pumps from it. For this file, drop a note to your Worthington District Office. Or write Worthington Corporation, Harrison, N. J.

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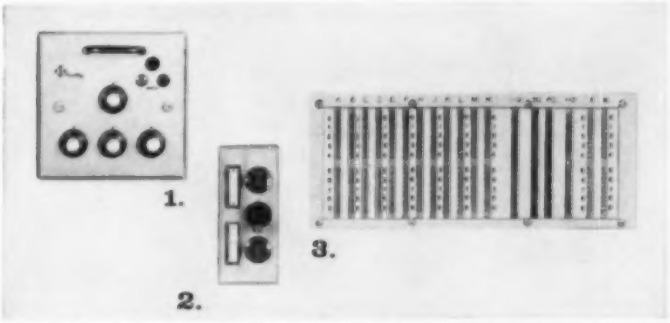

PowrMag systems embody the highest degree of flexibility. Simple, efficient electrical design utilizing long-lived and trouble-free solid state components, and rugged mechanical construction suit the system for a variety of industrial process control applications.

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This magnetic amplifier, operating on 1-9v DC, may be used individually, as a single 2 or 3 mode controller, or as one element in a large system. Each control unit may be removed from the front of the panel for easy interchangeability. The basic unit is easily converted to other modes by the addition of interchangeable, plug-in circuits for *all* common control operations. Inventory is reduced to the one basic unit. Unaffected by shock or vibration, PowrMag has no moisture, dirt, leakage or freezeup problems—3.5 watts of unregulated 110v, 60 cycle AC. Size—5¼" x 5¼".

2. *Remote Control Station*

These stations provide for remotely established set points and required manual control operations. Full station may contain two single or ganged potentiometers, one switch and two meters. Size—2¼" x 5¼". Half stations available with set point, bias or ratio dial and output signal indicator. Size—2¼" x 3⅛". Each station uses 12-wire, color-coded electric cable with MS-type connector. Front mounting and removal make it ideal for the compact console installations required for centralized control.

3. *Patchboard*

Interconnecting the system in any desired manner, via color-coded electrical cable, the patchboard requires no solder connections or terminal boards—all connections are made by special taper pins. Each connection is identified by an alphanumeric combination. Numbers, run vertically, identify the components in the system, such as magnetic amplifiers, controllers, transducers, etc. Letters, run horizontally, identify the connectors leading into the patchboard. DC control power bus is in the center section—no AC voltages are used in the patchboard.

Easy front access permits simple changing of operations. Additional loops or components are readily added to the system.

A letter or phone call will bring you complete information on the PowrMag system. **Ask for Bulletin MSP-163.**

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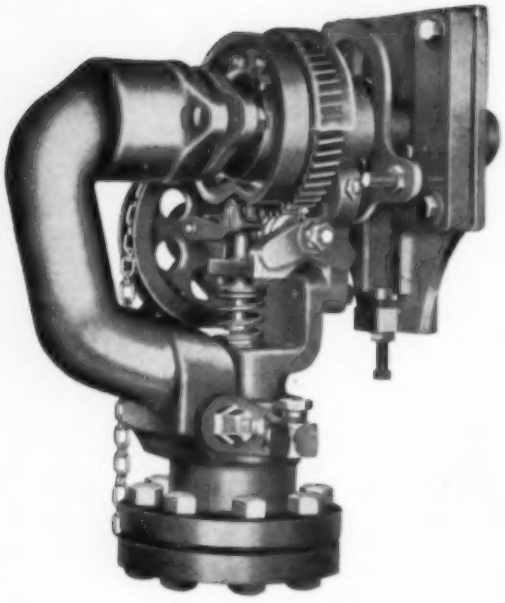

Quick Opening Bayer Soot Blower Valves Assure

- 100% cleaning efficiency
- minimum steam consumption
- superior high temperature resistance

The Bayer Balanced Valved Soot Blower is a single-chain operated design that assures precise sequential operation of the valve and element. *Only* after the start of full steam flow does element rotation commence—a feature which provides positive and efficient cleaning over the entire arc. . .without wasting steam.

The Bayer Soot Blower is simply operated by a pull on the chain which opens the cam-actuated valve. Continued pulling of the chain slowly rotates the element through its cleaning arc, at the end of which the valve automatically closes.

For severe high temperature locations, "super service" elements of Bayer-developed "Chronilloy" are available. Of superior strength, wrap-resistance, and stability, these elements resist the oxidation and chemical action caused by very high temperature gases.

In over fifty years of continuous specialized service, the Bayer company has equipped more than 35,000 boilers with dependable soot blowers. Engineered for long life and low maintenance, Bayer products assure economical and trouble-free operation.

ADVANTAGES OF THE BAYER BALANCED VALVED SOOT BLOWER

- single chain operation
- individual elements adjustable for high pressure service by orifice plate valve
- full steam pressure over entire cleaning arc
- selected gear ratios for optimum rate of element rotation
- minimum pressure drop through valve body
- machined air seal with spring loaded seat
- complete vacuum breaker protection
- precision swivel tube alignment lessens stuffing box packing needs
- load carried on ring type thrust bearings

For further information contact the Bayer representative nearest you. He is an experienced engineer, qualified to service Bayer Soot Blowers.

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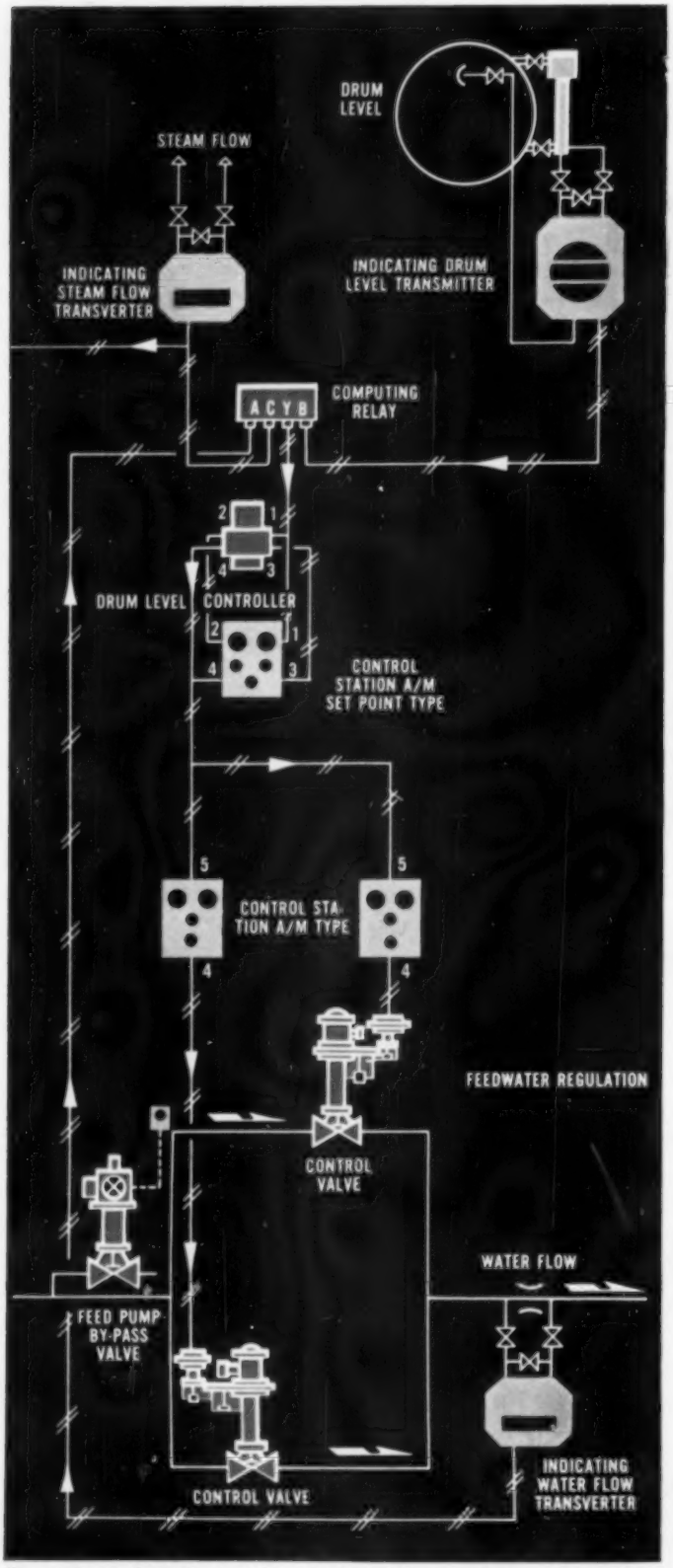
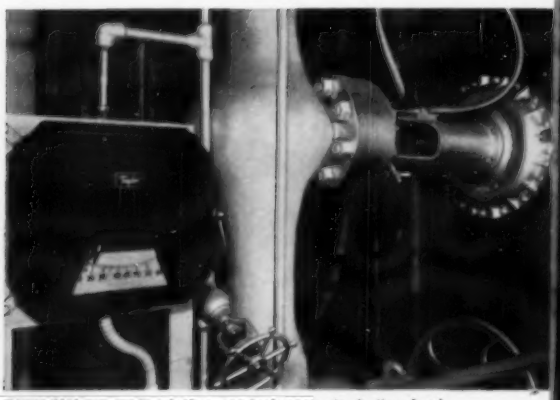
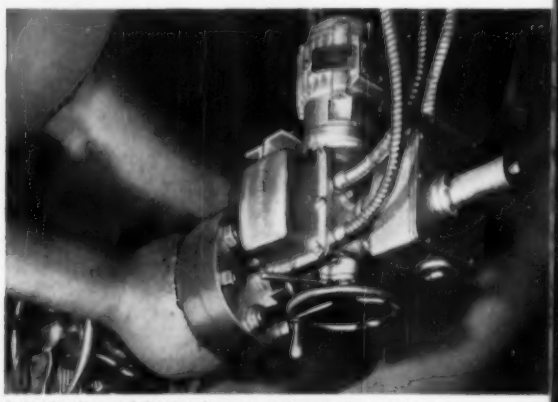


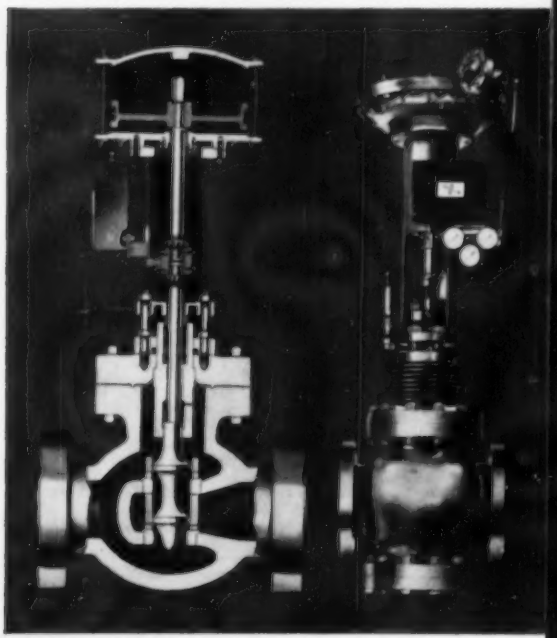
Three influence feedwater regulation is just part of a complete Copes-Vulcan boiler control system installed at a pace-setting utility station. Feed to boiler is modulated by steam flow, feedwater flow, and drum water level.



Copes-Vulcan recirculation control protects boiler feed pumps. When pump discharge falls below a certain level, a diaphragm-operated by-pass valve opens to assure sufficient flow to prevent overheating of the pump.



A feedwater and heater by-pass valve is shown above. Also, a Copes-Vulcan control valve is installed in each of the two main boiler feed lines. These valves handle pressure drops of over 2600 psig without difficulty.



Versatile control valves feature simplicity of design. Piston-type CV-P (left) is ideal for high-duty service. Diaphragm-type CV-D (right) is designed for remote control service. All Copes-Vulcan valves are tailored to the job.

COPES-VULCAN control valves make boiler feedwater systems accurate and trouble-free...

The big load changes of today's boilers put tremendous demands on the accuracy and dependability of feedwater and recirculation systems. Copes-Vulcan systems meet these demands with positive control, positive performance. ■ As long-time specialists in feedwater control, Copes-Vulcan has the experience and design know-how to custom-engineer control valves to rigid specifications. Regardless of high pressure drops, you get close control over full load range, without costly maintenance or replacement. ■ To the dynamic balance of the valves, Copes-Vulcan adds advanced instrumentation. The highly-responsive control system stabilizes water level regardless of changes in load or feed pressure. ■ Bulletin 1038 describes efficient boiler control at a key eastern power station. Write for your copy.
Copes-Vulcan Division, Erie 4, Pennsylvania.

Copes-Vulcan Division
BLAW-KNOX

Background photo shows Cooper-Bessemer FM compressors for soot blowing service in a large western utility.

ECONOMICS OF BOILER CLEANING WITH COMPRESSED AIR (Versus Steam)

1. Pressure is always adequate to do clean, thorough job.
2. Better programming with air . . . gets better cleaning results for higher boiler efficiency.
3. Lower cost for blowing medium . . . less waste.
4. No quenching action on hot alloy tubes or pressure vessels.
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6. Improved housekeeping . . . no steam or condensate leakage.
7. Greater over-all economy of blowing medium on evaluated basis.
8. Eliminates condensate makeup required when blowing with steam.

Soot blowing with air is faster, cleaner, less costly

...a report on soot-blowing applications by
L. B. Schueler, *Power Plant Consulting Engineer, The Cooper-Bessemer Corporation*

The big reason why power companies and their consultants are switching from steam to air for soot blowing is *to reduce costs.* Compressed air does the job more thoroughly, uniformly, with less mess and at less cost. Its high efficiency increases the capacity, availability and economy of the entire furnace and boiler! Total maintenance cost is very much lower.

The whole story is given in the reprint of an article, "Steam or Air: Which costs more for boiler cleaning?" Write for your free copy. We will gladly work with you on your plans for compressor facilities for soot blowing . . . or other power plant needs. Call the nearest office.

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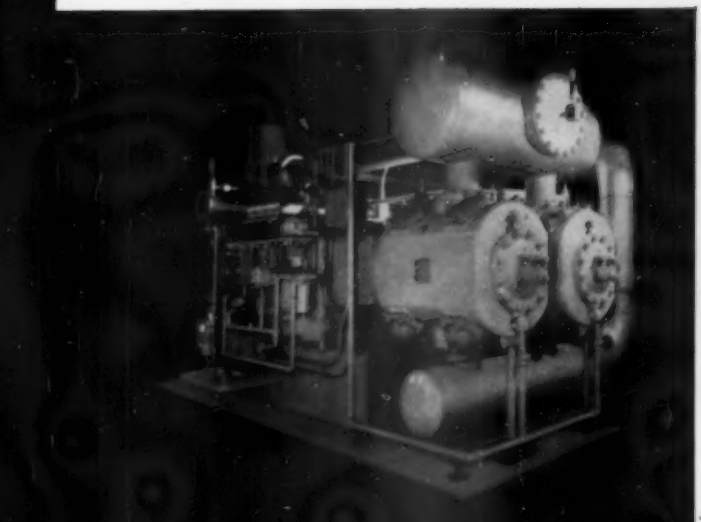

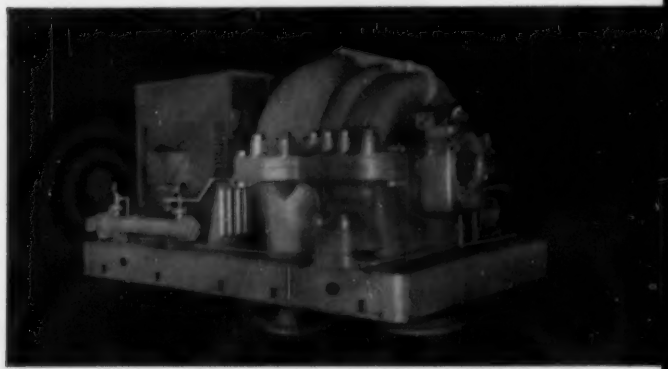

Multi-stage centrifugal compressor. Available from 7000 cfm and up.

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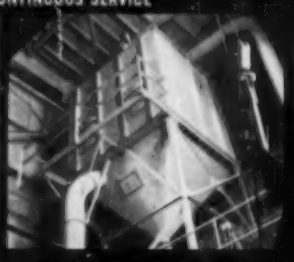

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GUEST EDITORIAL

Progress Through International Cooperation

Joseph H. Keenan

Prof. Joseph H. Keenan

Head, Mech. Engineering Dept.

MASSACHUSETTS INST. OF TECHNOLOGY

An international research program on the properties of steam directed toward pressures to 1000 atmospheres and temperatures to 800 C or 1500 F is now in operation. The earlier research program which culminated in the Third International Steam Table Conference in the United States in 1934 barely reached 300 atmospheres and 550 C or 1000 F. The new program, like the old one, will permit the tabulation of data to somewhat higher pressures and temperatures than the upper limits of the measurements with some degree of confidence.

About 1954 an awareness of a program of experimental research in the U.S.S.R. stimulated a renewal of interest resulting in the formation of the ASME Research Committee on the Properties of Steam. Similarly, research programs sprang up in Britain and Germany. More recently word has come from Japan of an extensive program beginning there. Analytical studies of data, requiring less capital expenditure than experimental studies, are in progress in all these countries and in Switzerland, Sweden and Czechoslovakia among others.

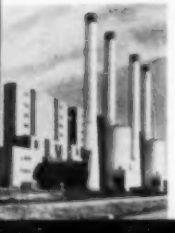
A new program of international cooperation is now in operation which resembles the program of 1929 to 1934. It differs in the important respect that the U.S.S.R. is playing a major part in it whereas no delegation from Russia appeared at any of the earlier conferences. A second difference is the introduction into the discussion of the transport properties, viscosity and thermal conductivity, along with the thermodynamic properties.

What have we to show for all this activity at the present moment? The answer is a somewhat limited amount of actual data, but a promise of an extensive array of interlocking data of various kinds. The existing new thermodynamic data consist of some measurements of pressure, volume and temperature to high pressures and temperatures by Kennedy in the United States and by Kirrillin and his coworkers in Moscow. Both of these are of great value but neither indicates any change greater than a fraction of one per cent from the numbers in the Keenan & Keyes tables. Extensive measurements of specific heat have been made in Russia. Sage at California Institute of Technology has developed a precision method for throttling experiments.

New steam tables have appeared in Russia and Germany, but these must be considered to be somewhat tentative. The advent of the computer has caused industry to exhibit a lively interest in algebraic statements of properties as distinguished from tabular data.

The existing new data on viscosity and thermal conductivity come from Keyes at M.I.T., Kestin at Brown University, and from Timroth and Vargaftik in Moscow. Knowledge of viscosity at pressures of a few thousands of pounds per square inch had been in a chaotic state with some sources differing by a factor of three or four. Thanks to the recent measurements, we are now concerned with differences of as many per cent.

This spontaneous international response to a peaceful Russian challenge has put us on the road toward a precise knowledge of one of the most important materials used by man. It is important not only because it is ubiquitous, but also because it is both typical and distinctive among vapors. It shows many typical relations between liquid, vapor and solid phases; but it also shows most interesting distinctive features as, for example, expansion upon freezing and a line of maximum density in the liquid phase. Exact data on water can be an infinite source of scientific information in our search for knowledge of materials of every variety.



President Eisenhower's National Conference on Water Pollution, the new Senate Select Committee on National Water Resources and a number of state legislatures are aware that the nation is facing . . .

A NEW PROBLEM —thermal pollution of this country's rivers. . .

"Local conditions govern the aquatic effects resulting from the discharge of the condensing water from a power plant to a river. Until more complete information is obtained, each case should receive individual study and treatment."

M. D. Engle

Pennsylvania Power and Light Co.

"Some states have placed a limitation on the maximum temperature of the water which can be discharged into its rivers and streams and other states are considering the enactment of similar legislation. However, such temperature restrictions are largely empirical in nature as there is not sufficient scientific information available at the present time to definitely indicate what temperature restrictions should be imposed."

L. W. Cadwallader

Potomac Electric Power Co.

"This . . . is of such great importance to the power industry, as well as to many of the large industries requiring great quantities of cooling water, that I think it should have the widest publicity. I am personally concerned that as a result of some of the activities by regulatory bodies, both at the state and federal level, inequities may occur unless the needs for all groups of riparian users are taken into account."

Sheppard T. Powell

Sheppard T. Powell and Associates

THE SOLUTION —will require time and effort.

This article presents results of one thorough approach to the problem. We hope that contemplated legislation will be based upon the results of equally serious studies and will avoid capricious or arbitrary limitations which might be unnecessarily punitive.

Effects of Heated Discharges on the Temperature of the Thames Estuary—I*

In the December 1954 COMBUSTION editorial the "thermal waste" problem confronting the then British Electricity Authority was commented upon, particularly because of its foreboding overtones. The problem, as we feared, has now caught up with U.S.A. industries. Accordingly we print here the best study we have seen to date on one phase of the problem—estimating the changes in temperature which follow any alteration in position or amount of heat discharged. The British, we mention in passing, have been moving very cautiously in their studies of this problem and have not, to our knowledge, set any temperature limitations as yet, six years after the problem was officially noted. First of two parts.

By A. L. H. GAMESON, H. HALL and W. S. PREDDY

Water Pollution Research Laboratory, Stevenage.

IN THE course of an investigation of the pollution of the Thames Estuary it was realized that temperature might be an important factor affecting the condition of the water, Note (1).[1] A number of electricity generating stations use the water of the estuary for cooling purposes and reject large quantities of heat to it. Calculation of the effects produced by the installation of new plant, or by changes in the discharge of heat from existing stations, requires a knowledge of the rate of exchange of heat between the water of the estuary and the air above it.

To find this rate of exchange of heat it is necessary to know how much the temperature has been raised by the heating, and, consequently, to know also what would have been the temperature in the absence of the heated discharges. This basic temperature depends on various meteorological factors, but it was thought that in any particular quarter of the year the relation between air and water temperatures might well be much the same from one year to another. Accordingly, an examination was made of the relations between the air temperature and the water temperature during periods when the artificial heating of the estuary was slight. The relations found were by no means precise, but the consistency of the results of calculations in which they have been used indicate that they are as accurate as can be expected.

Examination of the problem falls into five sections: measurement of the temperature of the water of the estuary over a period of several years; estimation of the temperatures that would have existed during the same period if no heat had been discharged; examination of the rate of entry of heat to the estuary; calculation of the rate of loss of excess temperature; and prediction of the temperature distribution for unit inputs of heat at points throughout the estuary.

Temperature in Presence of Heated Discharges

From 1949 to 1954 the temperature of the water of the Thames Estuary was measured from the Port of London Authority's launch "Shornmead" in the course of chemical surveys made by the Water Pollution Research Laboratory. These surveys were carried out weekly (except when the launch was being overhauled) and temperatures were taken at a depth of 6 ft., in midstream, at fifteen or more points from some miles above London Bridge to Southend—a total distance of about 50 miles.

The earliest measurements were made by placing a mercury-in-glass thermometer in the water remaining in a Casella sampler (a weighted brass container) after the bottle it contained had been removed. This method tends to give slightly erroneous results—particularly in the winter when the air is generally at a lower temperature than the water and there is also cooling by evaporation from the wet sampler while the measurement is being made.

In 1951, a method of measuring the temperature electrically was developed (2), use being made of thermally sensitive resistors formed from a complex mixture of metallic oxides; the resistors chosen were Stantel thermistors, type F2311/300 (3). The general use of thermistors in measuring water temperatures has been discussed in detail by Mortimer and Moore (4). Al-

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[1] Numbers appearing in parentheses refer to similar numbered References appearing at the end of the article.

though the apparatus to be used in the estuary was developed in 1951 it did not supersede the mercury thermometers until November 1952; thereafter it was periodically calibrated in the laboratory against an accurate mercury-in-glass thermometer. On two occasions in that month, when a total of forty-eight temperatures in the estuary were measured, both with a thermistor and with a mercury thermometer, the values obtained with the thermistor exceeded those found with the thermometer by an average of 0.09 C with a standard deviation of 0.14 C.

The average period of retention of the fresh water passing through the estuary is of the order of a month, and since the thermal capacity of the water is large and the rate of cooling is comparatively slow, it is considered best to make the calculations using average figures for a period of a few months. A period of three months was found to be the most suitable.

An effluent entering the estuary is not only displaced toward the sea by the fresh water flow, and dispersed by tidal mixing, but is also carried some way up and down the estuary under the action of the tide. The average range of this tidal excursion in the part of the estuary being considered is 8 or 9 miles, and it is evident that in obtaining the quarterly average distribution of temperature along the estuary it is essential to reduce all the figures to some common basis of tidal state. If there were a large number of temperatures taken at all states of the tide at one point in the estuary, the average temperature at that point could readily be found, but when there are only about thirteen readings taken at any point during the quarter this method is unsuitable, and consequently a different method was adopted. The individual temperatures were plotted against the position that the bodies of water from which they were taken would have occupied at half-tide; then, by drawing a smooth curve through the plotted points, the distribution of temperature at half-tide was found. To obtain the average distribution during the quarter, the temperature was read from each weekly curve at intervals of 5 miles along the estuary, the figures for each point were averaged and the average values plotted against the distance along the estuary. It may be mentioned that this method has also been applied successfully to figures for salinity (5) and oxygen (1).

Variation of Temperature Across the Estuary.—In the part of the estuary lying roughly in the 8 miles immediately upstream of London Bridge the temperature of the water at the side of the estuary is often appreciably different from that of the water in the center. The power stations in this neighborhood discharge their condenser water near the side of the estuary and the heated water flows close to the bank for a number of miles, gradually mixing with the water in the center. The difference in temperature is greatest just below the point of discharge from a large power station on the ebb tide, and just above it on the flood. The temperature difference varies greatly with the state of the tide, and if the positions where the temperature is measured in mid-stream are adjusted to the half-tide positions it is found that the temperature depends on the state of the tide.

Only a few measurements of these variations in temperature across the estuary were made during the survey, and the available information is insufficient for applying an accurate adjustment of mid-stream data to average conditions over the cross-section. The temperature of the water at the centers of the arches of the bridges in this neighborhood was measured from time to time, but there was no measurement of the amounts of water flowing through the different arches. To apply a correction it is necessary to estimate the temperature which would have obtained if the water had been completely mixed, and to find this accurately requires a knowledge of all the temperatures and all the velocities of flow in a cross-section. The relative discharges through the different arches were not measured, but were estimated approximately from the width of the arches, the depth of the water under them, and from the visible movement of the surface. The required average temperature of the water over the cross-section was then estimated. The corrections to be applied to the midstream temperatures were adjusted to half-tide positions and the average correction at each position was found; there were large variations in the calculated corrections. Fortunately the variation in temperature had been measured for the same tidal conditions as those when the temperature readings in the center of the estuary had been taken and are therefore representative of the same tidal conditions. The maximum correction which was used was less than 1 deg. C.

Temperature in Absence of Heated Discharges

It is to be expected that the average temperature of the water near the head of the estuary will be related, fairly closely, to the prevailing air temperature, while at the seaward end the temperature of the water will be determined mainly by that of the sea. Owing to its large thermal capacity the sea changes temperature only slowly, and consequently the changes in the temperature of the water at the bottom end of the estuary tend to lag behind changes in air temperatures. The differences between the mean temperature at the surface of the water near the mouth of the estuary and the mean air temperature at Greenwich during each month of 1930 are shown in Fig. 1.

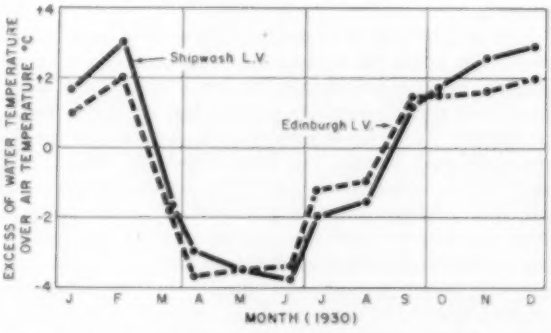


Fig. 1—Comparison between monthly average temperatures of the sea at two light vessels in the Thames Estuary mouth and of the air at Greenwich

The average temperature of the water at any point in an estuary receiving no heated discharges will not, in general, be the same as that of the air in contact with it. The water temperature will be lowered by evaporative cooling and raised as the result of insolation; there will also be exchanges of heat with adjacent bodies of water and with the bed of the estuary.

In the present work it was decided that the labor involved in calculating the equilibrium temperature of the water—on the basis of the humidity, temperature, wind velocity, intensity of sunshine, etc.—would be excessive, and that the results obtained thereby would be of doubtful accuracy. Instead, the relations that existed between the air and water temperatures before the estuary was appreciably heated were derived from the earliest apparently reliable data that could be found. Some data were found for the temperature near Teddington Weir which forms the landward limit of the estuary. Figures were also obtained for two points in the middle reaches—at Greenwich (23 miles seaward of Teddington Weir), and off Crossness (32 miles).† The temperature distribution seaward of Crossness was found from measurements made by the London County Council in the course of their regular chemical surveys.

Temperature at Teddington.—The earliest data found for the temperature of the Thames in the vicinity of Teddington are for January 1855 to June 1857 (6). These data give the temperature of the water measured daily at 9 a.m. at Kingston-on-Thames (about a mile upstream of Teddington) and recorded to 1 F—or sometimes to half a degree.

The monthly averages of these temperatures have been compared with the corresponding averages of the daily mean air temperature recorded at Greenwich Observatory (obtained from the Meteorological Office of the Air Ministry). A preliminary investigation showed that in all but one of the months the temperature of the water exceeded that of the air, and that the excess temperature tended to increase with increasing temperature. In the subsequent analysis the values for February 1857 were omitted since the average air temperature was −1.6 C which would lead to an expected water temperature of less than 0 C.

A partial regression equation was derived giving the predicted value, T'_w, of the temperature of the water in terms of the air temperature T_a, and the difference, A, between the value of T_a and its value in the previous month. The term in A was included in case the temperature of the water tended to lag behind that of the air. The equation for the predicted value of the water temperature was then found to be

$$T'_w = 0.64 + 1.072T_a + 0.011A \qquad (1)$$

where all the temperatures are in degrees C. The coefficient of A in this equation suggests a negative lag effect but it is not statistically significant.

The standard error of estimate was 0.56 C, compared with an error of 0.68 C for the simpler equation $T_w = T_a + 1.27$, and with a standard deviation of over 5 C in the observed values of T_w.

It may be noted that since the water and air temperatures are so closely related, this and subsequent regression work has been carried out using the excess temperature instead of the water temperature, that is, an equation of the form $(T'_w - T_a) = a + bT_a + cA$ has been obtained, and then rearranged to give the water temperature in the form

$$T'_w = a + (1 + b)T_a + cA$$

Using the regression equations to predict the water temperature in February 1857 the value found for T'_w is −1.13 C while the observed value was 0.64 C which gives an error in prediction over three times the standard error; this is highly significant and indicates that the equation does not apply when such low air temperatures are encountered.

From 1915 to 1921 the temperature of the Thames at Teddington was measured, once every two weeks, by the London County Council; since 1944 these measurements have been continued. If the quarterly averages of the L.C.C. readings for Teddington during the period from 1915 to 1921 are compared with the values given by the equation for Kingston, it is found that the standard error in prediction is 0.68 C, and that the average error is +0.05 C; this shows that the observed and predicted levels of the water temperature do not differ significantly. Since there are only about six readings for each quarter it is impossible to predict the observed values with any great accuracy, as these values will not necessarily be representative of the average temperature during the quarter. If the readings for 1944 to 1948 are included, the average and standard errors remain unaltered (figures for more recent years have not been used owing to the discharge of heat from Kingston Power Station). Now the standard deviation of the observed excess of the temperature of the water over that of the air is found to be only 0.69 C, so that the regression equation has no advantage over adding a constant amount to the air temperature to obtain the water temperature. The average observed excess for the four quarters of the year are 0.7, 1.8, 1.3, and 1.4 C, respectively.

Lacking more detailed information, the quarterly average temperature T'_T, of the Thames at Teddington, in the absence of artificial heating, will be assumed to be given by

$$T'_T = T_a + a \qquad (2)$$

where T_a is the corresponding average for the air temperature at Greenwich, and a is equal to 0.7, 1.8, 1.3, or 1.4 C for the first to fourth quarters of the year respectively.

Temperature at Greenwich.—During most of the latter half of the nineteenth century the temperature of the estuary in the neighborhood of Greenwich was recorded daily (7).

The earliest readings were taken using a maximum thermometer (mercury in glass, with a steel index) and a minimum thermometer (colored alcohol in glass, with a glass index). The thermometers were placed in a perforated wooden trunk fixed to the side of the "Dreadnought" Hospital Ship in such a way that the thermometers were about 2 ft below the surface of the water and 1 ft from the bottom of the trunk. The thermometers were read daily by the superintendent of the ship or, in his absence, by one of the officers. The daily readings began on May 13, 1844 after a preliminary experiment had shown that there was no appreciable vertical temperature gradient in the estuary at this point.

The records give the daily readings of each thermometer, and also the monthly averages except for 1844, 1845, and 1848 to 1855. From 1866 the index-error corrections to the thermometers are recorded; it appears that the corrections have been applied. On April 13, 1870, the readings were discontinued as "Dreadnought"

† Positions in the estuary are generally given with reference to London Bridge, which lies 19 miles below Teddington Weir.

ceased to be used as a hospital ship. Nine months later the trunk containing the thermometers was attached to the police ship "Scorpion" moored in Blackwall Reach, and observations were made by the resident inspector on board. In April 1872, the minimum thermometer was broken and replaced—this is the first mention of a change in thermometers. In May 1874, the trunk was moved from the "Scorpion" to the "Royalist" moored in the same place. In February 1875, both thermometers were replaced. In October 1879, the police ship "Royalist" was involved in a collision and placed on the bank, and the series of readings then terminated owing to the inability to find a suitable station for the thermometers.

In May 1883, the recording of Thames temperatures was resumed under the direction of the Corporation of the City of London. A Six's thermometer was placed 2 ft below the surface of the water at the end of one of the jetties of the Foreign Cattle Market at Deptford (4 miles below London Bridge). This series went on for eight years and the last readings were taken on June 13, 1891.

The Greenwich-Deptford readings therefore cover most of the period from 1844 to 1891, and those for 1856 onwards have been examined statistically in the same way as were the figures for Kingston. Groups of from three to five years have been taken, and partial regression equations obtained giving the excess of the temperature of the water over that of the air, in terms of the air temperature T_a, and the change A, in the value of T_a from the previous month. After rearranging, equations are obtained of the form.

$$T'_w = a + b_1 T_a + b_2 A \qquad (3)$$

The values of the coefficients b_1, b_2 and their standard errors of estimate are given in Table I:

TABLE I—COEFFICIENTS (AND STANDARD ERRORS) IN THE EQUATION $T'_w = a + b_1 T_a + b_2 A$, WHERE T'_w IS THE ESTIMATED TEMPERATURE OF THE WATER, T_a THE AIR TEMPERATURE, AND A THE CHANGE IN T_a FROM THE PREVIOUS MONTH; Sb IS THE STANDARD ERROR OF b

Position	Period	$b_1 \pm Sb_1$	$b_2 \pm Sb_2$
Greenwich	1856–1859	1.087 ± 0.022	−0.153 ± 0.037
Greenwich	1860–1863	1.125 ± 0.030	−0.169 ± 0.046
Greenwich	1864–1866	1.086 ± 0.034	−0.092 ± 0.050
Greenwich	1867–1870	1.054 ± 0.024	−0.126 ± 0.034
Greenwich	1871–1875	1.140 ± 0.023	−0.191 ± 0.033
Greenwich	1876–1879	1.084 ± 0.022	−0.106 ± 0.036
Deptford	1883–1886	1.111 ± 0.027	−0.130 ± 0.045
Deptford	1887–1891	1.069 ± 0.023	−0.179 ± 0.035

In Fig. 2 are drawn the regression lines for conditions when A is zero; the figure thus shows the excess of the water temperature over that of the air when the air temperature is steady—or, more precisely, the average excess to be expected during the second of two months with the same average air temperature. The line for 1867–1870 lies below the other lines to an extent that is statistically significant as the standard error of the mean excess temperature for this group is 0.11 C. The other lines lie close together, and although both the value of b_1 and of b_2 are rather higher for 1871–1875 than for the other groups, the discrepancy is not large enough to conclude that the readings of this group do not come from the same population as the remaining data. Since there is no reason to suppose that the excess temperature was actually half a degree lower during the years from 1867 to 1870 than during the rest of the period, and since the

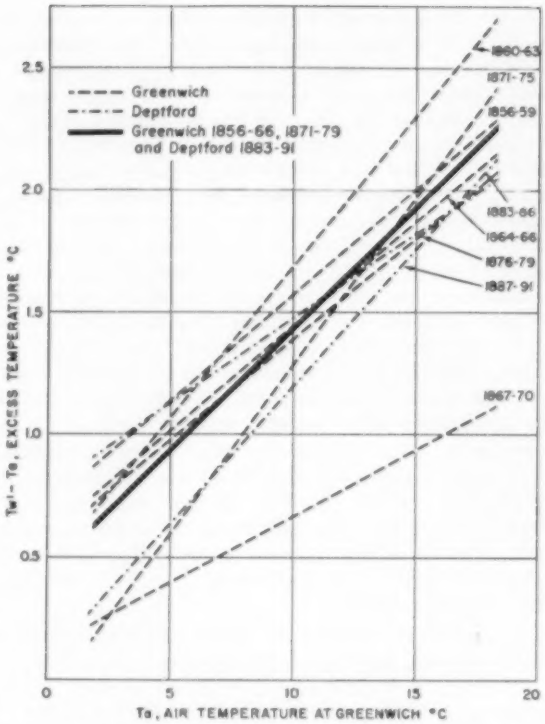


Fig. 2—Relation between the air temperature when this is steady and excess of water temperature over air temperature. Data from Table I with A put equal to zero. NOTE: Heavy black line is average of all dotted lines except 1867-1870

remainder of the lines agree well with those for Kingston from 1855 to 1857, and for Crossness from 1885 to 1895 (see below), it is assumed that the readings for 1867 to 1870 contain some systematic error. The data for Greenwich in 1856–1866 and 1871–1879, and for Deptford in 1883–1891, have been taken together, and the regression equation calculated as before. The equations for estimating the water temperature T_w is found to be:

$$T'_w = 0.41 + 1.101 T_a - 0.151 A \ ^\circ\text{C}$$

Although the coefficients in the regression equations for the different groups are substantially the same, the relations may not in fact be linear. Since an equation is required for predicting quarterly averages, it is advisable to see whether or not the mean errors for corresponding quarters differ significantly from zero. Taking all the quarterly averages that are available for the period 1856–1866 and 1871–1891 the average errors for the four quarters are found to be +0.20, −0.48, +0.10 and +0.16 C respectively. Now the population standard deviation of all the errors in the seventy-eight quarters used is equal to $\sqrt{\Sigma(T'_w - T_w)^2/77}$, or 0.50 C and for a group of twenty figures for corresponding quarters the standard error of estimate of the mean temperature will be $0.50/\sqrt{20}$, or 0.11 C. Accordingly, the average error of −0.48 C for second quarters must be considered to indicate that the true relation between T_w and T_a is not linear or that there is some other difference between this and the other quarters of the year.

The most suitable equation for the prediction of the temperature T_0, of the water in the vicinity of Greenwich and Deptford is therefore concluded to be ..... *p 37*

$$T'_o = a + 1.101T_a - 0.151A \text{ C} \qquad (4)$$

where a is 0.21, 0.89, 0.31, or 0.25 C for the first to fourth quarters respectively, T_a is the mean air temperature at Greenwich, and A is the average month-to-month change in T_a—that is, one-third of the difference between the value of T_a in the last month of the quarter and the last month of the preceding quarter. The standard error for the seventy-eight quarters using the four forms of this equation is 0.40 C.

Temperature off Crossness.—The regular recording of the temperature of the water of the Thames by the London County Council appears to have started in February 1885. From that date the series of readings for the Thames off Crossness—about 13 miles seaward of London Bridge—is almost complete. The temperatures are taken twice daily (once near high water and once near low water), in midstream at a depth of 6 ft. Readings are not taken on Sundays, on public holidays or in unsuitable weather.

The monthly averages have been treated in the same way as above. Dividing the data for 1885 to 1895 into three groups showed no significant difference between values of the coefficients obtained, and taking together all the monthly averages for the period of eleven years the regression equation found was.

$$T'_w = 0.40 + 1.098T_a - 0.272A \text{ °C}$$

The standard error of estimate was 0.57 C—for quarterly averages the expected error would be $0.57/\sqrt{3}$, or 0.33 C.

To check the equation, the quarterly averages of the temperature off Southern Outfall (Crossness) in 1912 to 1918 have been compared with the values given by the equation. The average error was found to be −0.04 C and the standard error 0.42 C.

Once again the average errors in the prediction by quarters have been calculated. Taking the errors for Crossness in 1885–1895 and Southern Outfall in 1912–1918, the average values for the four quarters are +0.26, −0.18, +0.12, and −0.08 C, respectively. After adjusting the equation to offset these errors, the standard error of prediction of the sixty-two quarterly averages is 0.36 C.

The equation that will be used for predicting the temperature, T_c, of the estuary 13 miles below London Bridge is therefore:

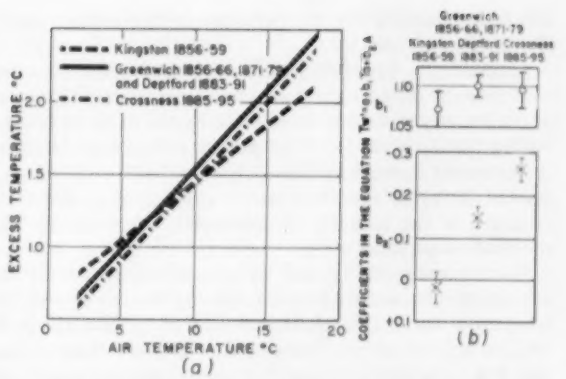
$$T'_c = a + 1.098T_a - 0.272A \text{ °C} \qquad (5)$$

where a is 0.14, 0.58, 0.28, or 0.48 C for the first to fourth quarters respectively.

Comparison of Regression Equations for Three Stations.—It is of interest to compare the regression equations for the three independent sets of data for Kingston, Greenwich and Deptford, and Crossness. The results of the comparison are shown in Table II and Fig. 3.

The closeness of the lines in Fig. 3(*a*) is remarkable, and shows that under conditions of steady air temperature (A equal to zero), the temperature at these three stations was nearly the same. In Fig. 3(*b*) it may be seen that while the values of b_1 do not differ significantly between the three sets of data, those for b_2 do—the further seaward the station, the more does the water temperature lag behind the air temperature.

Seaward of Crossness.—Temperature measurements of



(*a*) Combined results of Fig. 2, compared with data for Kingston and Crossness. (*b*) Coefficients in Equation (3) for three points in the estuary. The vertical lines show the range $(b+Sb)$ — to $(b-Sb)$ where Sb is the standard error of estimate b.

Fig. 3—Relation between the temperature of the Thames and of the air at Greenwich

the sea used to be made from the Edinburgh Light Vessel (Lat. 51 deg. 33 min North, Long. 01 deg 16 min East) which is about 76 miles seaward of London Bridge. This point should be far enough out to be unaffected by the artificial heating of the Thames but not so far out that conditions are likely to be very different from those in the lower reaches of the estuary. The readings relate to the temperature of the surface of the sea and were recorded twice daily—at or about sunrise, and at 4 p.m.; the temperatures are generally given to 1 F.

Unfortunately no observations of sea temperature have been made from Edinburgh Light Vessel since May 1940. No attempt has been made to relate the available data to the air temperature at Greenwich. Since the war the nearest observing stations to the Thames have been Shipwash Light Vessel (52 deg 02 min North, 01 deg 42 min East) and Galloper Light Vessel (51 deg 44 min North, 01 deg 58 min East); both these vessels lie nearly 50 miles seaward of the Edinburgh and quarterly averages of sea temperature do not bear a simple relation

TABLE II—COEFFICIENTS (AND STANDARD ERRORS) IN THE EQUATION $T'_w = a + b_1Ta + b_2A$, WHERE T'_w IS THE ESTIMATED TEMPERATURE OF THE WATER, T_a THE TEMPERATURE OF THE AIR AT GREENWICH, AND A THE CHANGE IN T_a FROM THE PREVIOUS MONTH. TEMPERATURES IN DEG CENT

Station	Kingston	Greenwich / Deptford	Crossness
Miles from London Bridge	20 above	4 below	13 below
Period	1855–1857	1856–1866, 1871–1879, 1883–1891	1885–1895
Number of monthly averages used in analysis	28	276	118
a	0.61	0.41	0.40
b_1	1.072	1.101	1.098
Sb_1	0.025	0.019	0.011
b_2	0.011	−0.151	−0.272
Sb_2	0.040	0.015	0.018
T'_w when $T_a = 10$, $A = 0$	11.33	11.42	11.38
T'_w when $T_a = 20$, $A = 0$	22.05	22.43	22.36

to each other (see, for example, Fig. 1), or in the pre-war period to those of the Edinburgh. It would appear that there are no suitable readings of sea temperature with

which to compare the temperature of the estuary since the middle of 1940.

Accordingly, the distribution of temperature seaward of Crossness that would exist if no heat were discharged to the estuary has been assumed to be the same as existed during 1915 to 1921. This period was chosen because the frequent surveys of the estuary made by the L.C.C. started in 1915, and because it appears that the temperature of the estuary off Crossness began to rise appreciably soon after 1921.

Each quarter of the year was examined in turn. The average temperature at each sampling station was calculated from the L.C.C. data and plotted against the position in the estuary. Smooth curves were then drawn through each set of points and the temperature read off at intervals of 5 miles from 15 to 45 miles below London Bridge—the curves for the second quarters are shown in Fig. 4. The average change in temperature from Crossness to each 5-mile point was then found for all the corresponding quarters and the results plotted, as in Fig. 6. The period covered was from the fourth quarter of 1915 to the fourth quarter of 1921, inclusive, but excluding the first quarter of 1920 for which there was insufficient information.

Production of Basic Temperature Curves.—To obtain a curve showing the temperature—which may conveniently be called the basic temperature—that would be found in the estuary under existing conditions of air temperature, if there were no discharge of heat to the estuary, the following procedure has been adopted. The predicted temperatures at Teddington, Greenwich and Crossness have been found by means of Equations (2), (3) and (4), respectively, and plotted against the position in the estuary. The appropriate curve from Fig. 6 has then been added, and a smooth curve drawn through the point for Teddington and between those for Greenwich and Crossness. Two examples of such curves are shown by the broken curves of Fig. 5 where curves for the observed temperature are also shown. It may be noted that the separation of the broken curves for 1919 and 1953 does not represent any general rise in temperature during the intervening years but only that the fourth quarter of 1953 happened to be warmer than the fourth quarter of 1919 by, on the average, some $3^1/_2$ C. The separation of the broken and continuous curves for the fourth quarter of 1953 shows the degree of heating of the estuary during that quarter, while the difference between the two curves for 1919 suggests some heating but indicates also the order of accuracy obtained in calculating the basic temperature from the air temperature; the accuracy of the observed data for 1919 is not known—the temperatures were recorded for the purpose of calculating the solubility of oxygen in the water and were not intended to show accurately the distribution of temperature through the estuary.

Rate of Entry of Heat

It is convenient to consider the various sources of heating under five headings, namely, power stations, industrial effluents, sewage effluents, fresh water discharges, and biochemical activity. Each of these will be examined briefly.

Power Stations.—Detailed information of heat discharged from power generating stations to the estuary during 1951–1954 and for four earlier years was supplied

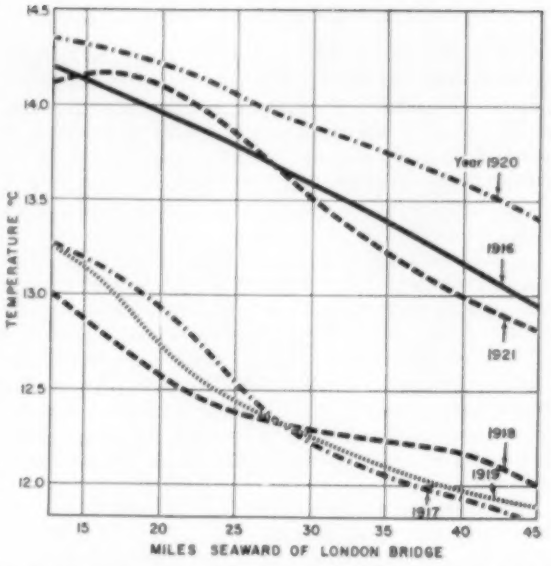


Fig. 4—Average temperatures in the Thames Estuary during the April-June quarters of 1916 to 1921

by the Central Electricity Authority. The average quantity of heat lost to the river per kilowatt-hour generated is known for each station and so is the quantity of electricity produced. To these figures have been added the heat from the London Transport Executive's generating stations at Lots Road and East Greenwich, and from the generating plant of the Ford Motor Company at Dagenham. The average rate of discharge of heat from all these power stations during 1951–1954 is estimated to have been 228×10^9 Btu per day, of which 73 per cent came from the five largest stations—the names of these stations are given in Fig. 7, where the amounts contributed by the individual stations are shown. There is less power generated during the summer than in the winter and the relative quantities for the four quarters of the year, expressed as percentages of the mean value, are 114, 90, 85, and 111, respectively.

Industrial Effluents.—The chief sources of heat under this heading are gas works, paper mills and sugar refineries. The information has been obtained mainly

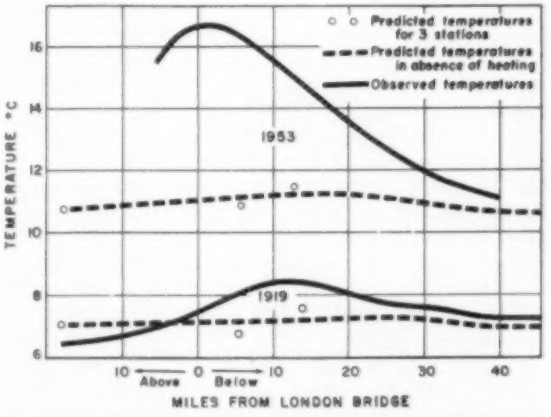


Fig. 5—Comparison between observed temperature of the Thames Estuary during the October-December quarters of 1919 and 1953 and the temperature calculated for the same quarters in the absence of artificial heating

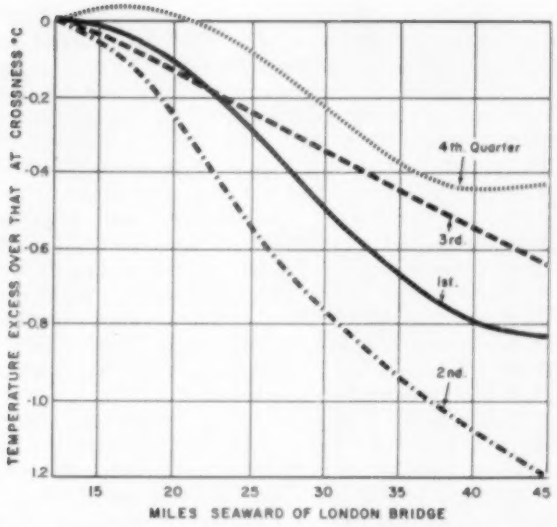


Fig. 6—Average distribution of water temperatures seaward of Crossness during corresponding quarters of 1915 to 1921

from the North-Thames and South-Eastern Gas Boards, the Port of London Authority, various firms concerned, and from measurements and estimates made by the staff of the Water Pollution Research Laboratory. Few of the figures are very reliable, flows of condenser water are often known only approximately, and figures for the increase in temperature of effluent over influent may be in error by more than 20 per cent. For the largest sources of heat, efforts have been made to obtain information that is relatively more accurate than for the smaller discharges.

Where condenser water is taken from the river and returned to it after heating, the heat discharged is the product of the flow with the increase in temperature. Where process water is taken from wells, or from the water mains, the heat discharged is taken to be the product of the flow with the excess of the temperature of the effluent over that which would exist in the estuary, at the point of discharge, in the absence of all heated effluents.

The total heat discharged direct to the estuary from these industrial sources is estimated (from data relating mainly to 1952–1953) to be 19.4 × 10^9 Btu per day.

Sewage Effluents.—At the Northern Outfall Sewage Works of the London County Council the temperature of the effluent from the activated-sludge plant has been recorded each weekday since 1949. To obtain an indication of whether these temperatures are representative of the average temperature of the final mixed effluent, two recording thermometers were installed for one week by the Water Pollution Research Laboratory; no significant difference was found between the average temperature of the final effluent and the L.C.C.'s figures which, accordingly, have been used in calculating the heat discharged to the estuary. Taking the average of the products of the mean quarterly flow of effluent with the corresponding excess temperatures, the average rate of entry of heat during 1949–1952 is found to be 14.0 × 10^9 Btu per day.

Similar and even less accurate calculations were made for the Southern Outfall Works of the L.C.C., Mogden Purification Works, and the other sewage works discharging their effluents to the estuary. The final estimate for all the sewage effluents was 27 × 10^9 Btu per day—during the summer the rate is probably not more than 8 units, while in the winter it may be 40 units. It may be noted that perhaps a substantial proportion of this heat comes from industrial discharges to the sewers—the figure given above for industrial discharges applies only to discharges direct to the estuary.

Fresh Water Discharges.—The remaining sources of heated water are the Upper Thames (entering over Teddington Weir) and the numerous tributaries which discharge direct to the Thames estuary.

The heat entering at Teddington is the most uncertain quantity. If the flow is 4000 million gallons†† per day (m.g.d.)—a flow that was approximately the average during the first quarter of 1951—and there is an error of 1 C in either the observed or the basic temperature, the resulting error in the rate of entry of heat will be 72 × 10^9 Btu per day. Now it was stated above that the temperature at Teddington showed no significant increase from 1855–1857 to 1915–1921 and 1944–1948, so that it is reasonable to assume that the heat entering over Teddington Weir was not great up to 1948. The average rate of discharge of heat from Kingston Power Station during 1951–1954 was 10.3 × 10^9 Btu per day, and, using the rate of loss of heat found later in this paper, it is found that, on the average, in traveling the mile from the power station to the weir at Teddington roughly 2 per cent of the heat is lost. No other appreciable sources of heat in this vicinity have been brought to notice and it will be assumed that the heat entering from the Upper Thames is 10 × 10^9 Btu per day.

Of the tributaries only the Wandle and Lea appear to contribute appreciable quantities of heat. The temperatures have been found from measurements made roughly once a week for a period of about two years from 1951 to 1953 by the Water Pollution Research Laboratory. The average contribution from the tributaries is esti-

†† Note: Throughout the paper Imperial gallons are used; to convert to U. S. gallons add 25 per cent.

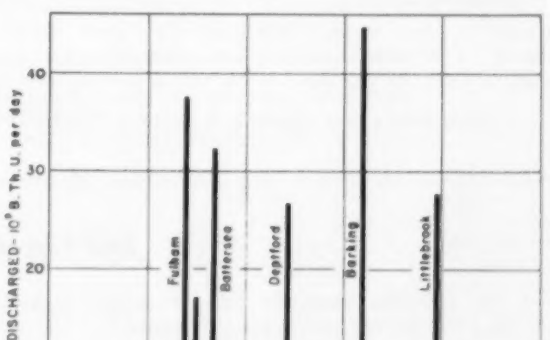


Fig. 7—Average rate of discharge of heat from Thames-side generating stations of the Central Electricity Authority during 1951–1954

mated to be a further 10×10^9 Btu per day.

Biochemical Activity.—The oxidation of organic matter is an exothermic process. For compounds consisting solely of carbon, hydrogen and oxygen, the heat released in oxidation to carbon dioxide and water is about 10^5 calories for each gramme molecule of oxygen consumed. For instance, the average value for methane, methanol, ethanol, glucose, sucrose, benzene, acetone, and acetic acid is found to be 108,800 cal/mole of oxygen, with a standard deviation of less than 4000. For compounds containing nitrogen the variability is greater, but the mean value is roughly the same as before. It seems reasonable to suppose that the heat generated in the water of the estuary, as a result of the biochemical oxidation of organic matter, will be of the order of 10^5 calories for each gramme molecule of oxygen which enters through the surface, and for each gramme molecule which enters the estuary in solution (from the Upper Thames, the sea and other sources) and is subsequently used in oxidation. Converting this figure to more suitable units gives 0.014×10^9 Btu per ton of oxygen.

From a consideration of the balance of oxygen in the estuary as a whole, it is found that the total rate of entry of oxygen is roughly 840 long tons per day (1), which indicates an average rate of heating of about 12×10^9 Btu per day.

Summary.—The various estimates given above are summarized in Table III, where the data from power stations are for 1951–1954 and most of the others are for 1951–1953. The total heat is 306×10^9 Btu per day. From this table it is seen that errors of, say, 20 per cent in the figures for the heat discharged from the smaller industrial discharges will have little effect on the accuracy of the work.

TABLE III—AVERAGE RATES OF ENTRY OF HEAT TO THE THAMES ESTUARY, IN UNITS OF 10^9 BTU PER DAY

Source of heat	Heat units	Percentage of total
Power stations	228	74½
Industrial effluents	19	6
Sewage effluents	27	9
Fresh water discharges	20	6½
Biochemical activity	12	4

The heat from the fresh water discharges is attributable mainly to power stations which use the Upper Thames and River Wandle as sources of cooling water; consequently over 75 per cent of the total heating of the estuary is due to power stations; in the summer the proportion is more than 80 per cent.

The degree of pollution of the Thames has changed during the past century; it is probable that only about five of the fourteen heat units considered under biochemical activity should be included in the increased heating. Most of this heating will take place in the middle and lower reaches of the estuary, where its effect will be small; the quantity of heat involved being both small and uncertain, it has been omitted from the calculations.

Most of the sewage effluents have been neglected since their effects also are small and uncertain. The Mogden and Northern Outfall waters contain heated industrial wastes, and it is probably best to consider all the heat from Mogden and part of that from Northern Outfall as sources of heat that did not exist previously.

Heating to Be Considered in Subsequent Calculation.—In the calculations that follow, the excess of the observed temperature over the basic temperature is related to the input of heat to the estuary. Clearly the heating that was present when the temperature measurements used in calculating the basic temperature were made must be omitted from the sources of heat. The basic temperature data have come from various periods, and from a consideration of the changes that have occurred in the past century it was concluded that the most suitable method of approaching the problem was to use all the sources of heat given above, with the exception of the biochemical activity and some of the sewage effluents.

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This article will conclude in January* COMBUSTION *with calculations on "Rate of Heat Exchange"

New Packaged Power Plant

J. M. Costello, executive vice president of South Carolina Electric & Gas Co. recently announced the purchase of four General Electric gas turbine package power plants.

Mr. Costello said that the use of natural gas as a fuel was an important consideration in his company's interest in the GE package plant because South Carolina Electric and Gas has recently installed more than 200 miles of natural gas transmission lines in its 23-county service area.

The new General Electric gas turbine package power plant is a compact, self-contained generating station capable of operating on a system in conjunction with other generating equipment, or at a completely isolated location. It can start without any external source of power and can be on the line at full load in approximately 15 min.

The overall dimensions of the installed package power plant are approximately 80 ft long and 35 ft wide. The plant has a net station rating for peak-load service of 10,750 kw. It is a complete and integrated power plant consisting of two basic units plus accessory equipment.

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PIPING FABRICATORS AND CONTRACTORS

The Bureau of Mines studies on the coal fired gas turbine employs a 1350 F gas under 80 psig pressure with a dust loading of 10 gr per 100 std cu ft. No commercially available precipitator is built for service over 1000 F so the Bureau has put together a laboratory-scale unit which so far indicates a high efficiency of collection at temperatures of 1500 F and under 100 psig pressure.

Precipitators in New Operating Range

By C. C. SHALE,* A. S. MOORE†

Bureau of Mines

U. S. Department of the Interior

THE FEDERAL Bureau of Mines has begun studying electrical precipitation of dust at temperatures and pressures well above the conventional operating range. If operation at these conditions proves practicable, sensible heat in process gases can be conserved for utilization in subsequent process steps. Although the Bureau's primary interest is in removing solids entrained in the gases from partial or complete combustion of coal, precipitators operating at these conditions may have economic application for removal or recovery of fine solids entrained in the product or waste gases in varied other manufacturing processes.

Bureau research engineers at Morgantown, W. Va., are setting up a gas turbine designed to generate 3750 excess horsepower using combustion gases directly from a coal-fired combustor. The working gas, carrying about 10 gr of dust per 100 std cf, enters the blade path at about 1350 F and 80 psig, and previous work by Bituminous Coal Research, Inc. shows blade erosion can be serious under these conditions (1).[1] It is hoped that new blade design and careful choice of materials will reduce erosion to tolerable limits; if this fails, dust must be removed from the working gas without cooling.

Conventional dust-removal apparatus will not adapt to the problem. Because of immoderate temperature and pressure loss, filters are impractical; cyclone separators are not efficient enough, and pressure loss in centrifugal separators is excessive. Electrical precipitators are ideal, from the standpoint of fluid mechanics, but no design specifications are available for the pressure-temperature combination imposed by the turbine gas.

Past work indicates that electrical precipitation at temperatures over 1000 F will be difficult (2) and may be impossible if resistivity of the dust becomes so low that the dust will not bind to the precipitator wall (3). Technology of the art, however, is highly empirical; relationships by which precipitator performance is predicted reflect only the conditions under which they are derived and are extrapolated to higher temperatures and pressures with little assurance of reliability. Consequently, the study on operating practicability of precipitators was undertaken on laboratory-scale equipment at temperatures and pressures to 1500 F and 100 psig, respectively.

Fig. 1 is a close-up of the dust feeder with components identified. One-hundred std cfh air passing through the pickup line carries dust from the feeder orifice, through the sight glass and elutriator to either precipitator, scrubber, or calibrating sampler. Feed rates from 2 to 4000 grains per hr are reproducible at any pressure to 100 psig, depending on choice of feeder-orifice size, pressure drop across feeder orifice, and degree of elutriation.

The air preheater and precipitator are shown in pro-

* Chief, Gas Purification Section.
† Supervisory Chemical Engineer.

[1] Numbers in parentheses refer to similarly numbered entries in the List of References at the close of the article.

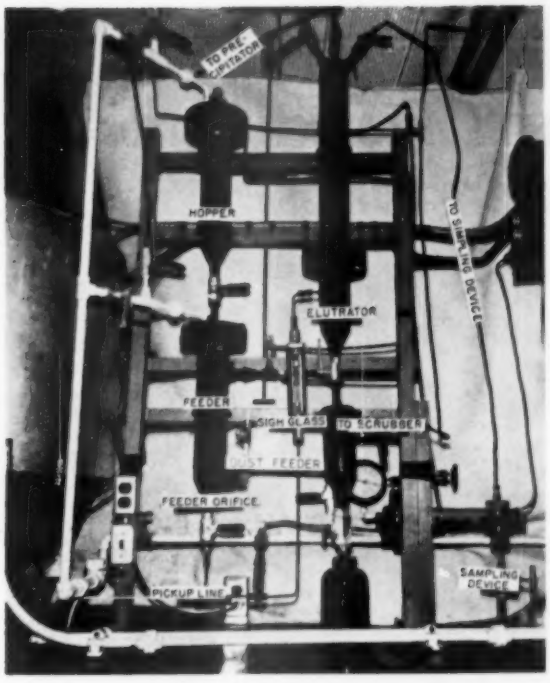

Fig. 1—The major components of the dust feeder for the laboratory set up are labeled at left

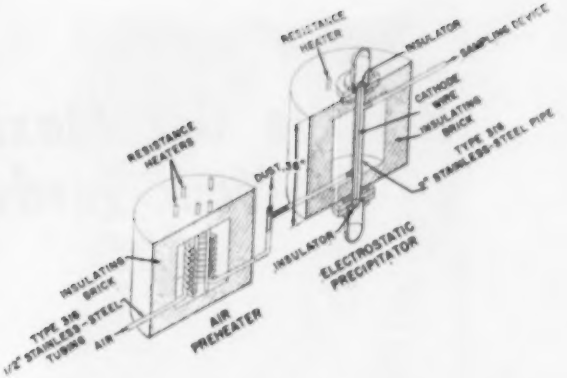

Fig. 2—All elements in the heat zone are schedule 80, type 316 stainless steel

jection, Fig. 2. All elements in the heat zone are schedule-80, type-316, stainless steel. The preheater coil is about 105 ft long and is directly connected to the precipitator tube which has flange closures, and the dust-carrying line connects with the crossover between them. Dust enters the precipitator tube tangentially and leaves radially. Electrical insulators and cathode wire supports, integral to the flanged ends of the tube, carry a 0.015-in. diam cathode wire providing a 30-in. energized section. Power for the unit comes from a 20,000 v, d-c, 60 cycle, vacuum tube rectifier. Resistance heaters in the preheater, precipitator, crossover, and dust line provide air temperatures to 1600 F at pressures to 100 psig.

The sampling probe is a $^1/_4$-in. tube concentrically located in the downstream end of a 3-ft section of 1-in. pipe. The tube end is flared to $^1/_8$-in. width that extends over the vertical diameter of the pipe. The probe connects through a type G, (4) porous stainless-steel filter to a vacuum pump that is controlled to equate air velocity in probe and pipe. Total dust passing the precipitator is calculated from the ratio, filtered dust:probe area::total dust:pipe area.

Some preliminary results on removal efficiency of the laboratory-scale precipitator are given in Table I. Ash used in these tests was 90–95 per cent less than 10 microns as determined by microscopic analysis (5).

Both coal residue and fly ash were used in tests to 900 F; above 900 F only fly ash was used. Dust concentration in the feed gas is calculated by relating the weight of solids recovered in the precipitator, the total gas flow and the dust concentration in the exit gas. The latter is calculated from the weight of solids collected in an isokinetic sampler as related to total gas sampled. Removal efficiency is calculated on the basis of gross weight of solids removed at an actual air velocity of 5 fps.

TABLE I—PRECIPITATOR EFFICIENCY AT GAS VELOCITY OF 5 FEET PER SECOND

Dust conc. in feed gas, gr/100 scf	Temperature, F	Pressure, psig	Dust conc. in exit gas, gr/100 scf	Removal efficiency, wt-pct
55.5	600	20	0.7	98.7
45.3	600	35	0.5	98.9
168.4	900	5	0.5	99.7
116.1	900	50	0.8	99.3
32.2	900	80	0.1	99.7
239.7	1200	50	0.7	99.7
158.0	1200	65	0.1	99.9

When tests at 1500 F on the laboratory-scale precipitator have been completed, a pilot-scale model will be constructed and operated to study further the effects of higher gas velocities and pressures. From this study information should be available enabling scale-up to commercial size of precipitator that will remove dust from the working gas driving the gas turbine. Bureau engineers hope also to gain insight into the practicability of specifying precipitators for service downstream from units operating to 30 atm, such as coal-oxygen, synthesis gas generators.

Results of these investigations will be described fully in future Bureau of Mines publications.

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How to Get Maximum Protection for Your Feedwater Pumps

Modern feedwater pumping systems with higher pump speeds, higher pressures and water velocities require more precise protection than conventional systems. The author offers an effective pump protection system at minimum cost and with good flexibility in piping design.

By W. G. HEGENER†

EDWARD VALVES, INC.*

IDEAL economic protection for high-capacity feedwater pumping systems is a combination of a tilting disk check valve in series with a stop-check valve. The factors that could cause one type of check valve to malfunction are not the same ones to which the other is vulnerable. Using two different types of valves, therefore, minimizes the chance that a given set of conditions will interfere with complete pump protection.

Check valve malfunction is receiving more attention today than a few years ago because of the higher pressures and water velocities involved and much greater dollar investments in pumping equipment. A few years ago, a piston check valve and a stop valve were considered adequate. Feedwater velocity was around 10 to 12 fps. Most pumps were 3600 rpm type. When a pump was turned off, the check valve had a comparatively long time to close while the pump was coasting to a stop.

Today, many pumps are high-speed types, operating anywhere from 6000 to 9000 rpm. Discharge pressures are as high as 5500 psi. Along with the increase in pump speed, pump inertia has dropped. In fact, doubling pump speed reduces inertia to $^1/_{16}$ of original value. Now, when the motor starter opens on an electric-motor-driven pump, pumping stops within one second. Because low-inertia pumps are very easily reversed, check valves must close quickly to prevent reverse flow and reverse rotation of pumps.

To keep feedwater piping costs reasonable, piping diameters have been held down. But feedwater velocity has risen sharply. Velocities as high as 20 fps are becoming common.

Finally, consider the cost of present-day feedwater pumping equipment. Boiler feed pumping equipment is one of the most expensive items—outside of the boiler and turbines—in the steam power plant. Systems for the average size generating unit cost hundreds of thousands of dollars for motor, fluid coupling and pumps.

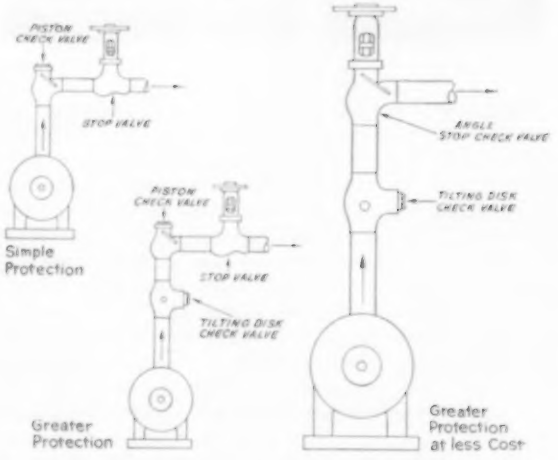

Fig. 1—Piping diagram—protection methods for boiler feed water pumps

Have Five Requirements

The changes in feed pump protection requirements suggest several criteria for check valve design:

(1) Close as quickly as possible after a pump is shut down, completing closure just as the forward motion of the water reaches zero, or as close to this condition as possible. (This means that the valve disk should have minimum inertia.)
(2) Open and be stable at flow rates equal to normal minimum low-load operating conditions for the particular installation.
(3) Give tight closure after many operations.
(4) Have low pressure drop to cut pumping costs.
(5) Be field repairable if at all possible.

Because it is impossible to combine effectively all these requirements in a single valve, it is best to use two basically different check valve designs: the piston check valve and the tilting disk check valve.

* Subsidiary of Rockwell Manufacturing Co., East Chicago, Ind.
† Executive Engineer

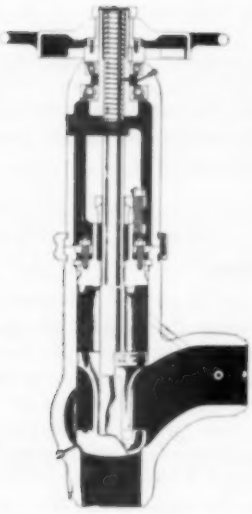

Fig. 2—Cross section, angle stop-check valve

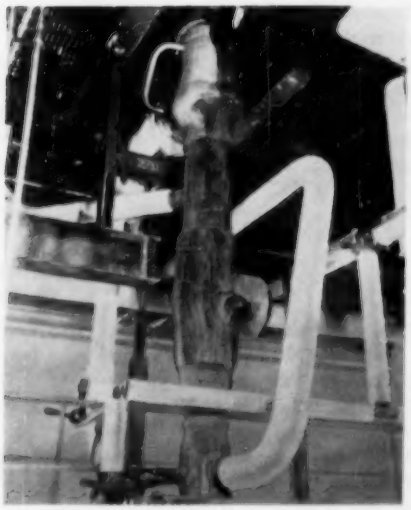

Fig. 4—Typical installation, feedwater protection system—from bottom of photo: pump discharge, tilting disk check valve, angle stop-check valve. (Photo made during piping installation.)

Why Tilting Disk?

Flow tests have shown that the tilting disk check valve with seat at 90 deg to flow closes regardless of the amount of welding chips, scale or dirt in the line. This is a most important feature. Tests show that water flow of 20 fps will sweep along particles up to $^1/_8$ in. diameter. During tests with water velocities up to 27 fps and under grit conditions at least 100 times more critical than any boiler feed pump system would meet the tilting disk check never stuck or failed to close.

The tilting disk valve closes rapidly due to its low inertia and spring-assisted action. The valve opens easily, has a one-piece body with pressure-seal bonnet and hinge pin covers. It can be installed vertically or horizontally.

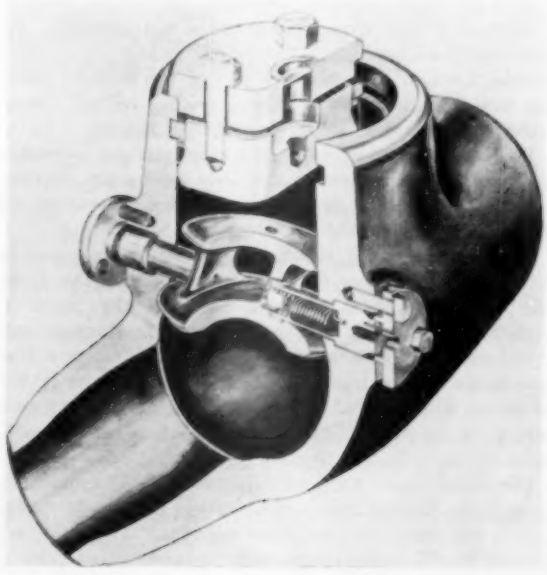

Fig. 3—Three-quarter cutaway, tilting disk check valve

Why Piston Check?

When feedwater velocities are 10 to 12 fps and where precautions are taken to keep feedwater clean, the piston check valve gives good protection. It reaches full-open position quickly, has excellent stability, closes tightly after thousands of operations and can be serviced in the field more easily than any other type of check valve.

Where feedwater velocities are high and high speed pumps are used however, greater diversity of protection is recommended for the feedwater pumps.

The simple solution to the problem of greater diversity in protection for the pumps is to use a tilting disk check valve in combination with the piston check valve. The valves complement each other in service characteristics. Possibility of system hang-up is minimized using these valves of different design characteristics.

In order to get the advantages of the piston check valve and be able to isolate the pump without adding a third valve at the pump discharge, the stop-check valve is recommended.

Stop-check Valve Holds Cost Down

A solution that provides maximum protection with economy is the combination of a stop-check valve and a tilting disk check valve. This offers the following advantages:

(1) Uses both types of check valves for maximum protection.
(2) Does not increase the number of valves.
(3) Provides a tight seating globe stop valve for isolating the pump.
(4) Allows greater flexibility in piping arrangements by use of horizontal or vertical tilting-disk check and a globe or angle pattern stop-check valve.

The Interlock Scheme

The stop-check valve can be motorized and an electric interlock system added. This interlock can be designed

to initiate closing action on the stop-check valve when the boiler feed pump control switch is opened and simultaneously start a time delay relay which will open the boiler feed pump motor circuit breaker after the relay has timed out. The objective of this scheme is to free the piston in the stop-check valve if there is any tendency to stick *before* the pump motor is stopped. This control is compatible with good power plant practice.

In view of present-day pump protection requirements the stop-check valve in combination with a tilting disk valve has powerful advantages which reduce to a minimum the probability of failure and provides this extra protection at minimum cost.

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*Engineering Education in Our Age**

By Theodore von Karman

The great British engineer Rankine was credited as saying, "A practical engineer is a man who perpetuates the mistakes of his predecessors," making Rankine among the first believing the transmission of empirical data, was not enough.

You cannot say anything against empirical data, Mr. von Karman went on to say. For example, hydraulics, which he once somewhat irreverently called "the science of variable constants," could not start with the real theory of hydrodynamics.

Even now we are not so far that we understand all the phenomena of turbulent motion. And after all, rivers and most motion in pipes and channels are turbulent motions. A great German scientist said that before he dies he would like to understand the Quantum Theory and the laws of turbulence. However, if he cannot accomplish this in his lifetime, he hopes that his Creator will explain the Quantum Theory, Period!

Thus in many fields empirical data and empirical rules are very important. However, we must know exactly for which cases we want empirical data and in which domains they can be employed.

Some people say an engineer is a scientist. This, Mr. von Karman felt is not quite correct. The purpose of engineering education is not only to educate scientists. After all, the engineer is a man who creates—not only ideas, not only theories, but also bridges, machines, airplanes—what the aeronautical industry calls "hardware." And his purpose is creating hardware. So do not underestimate the engineer's faculty and talent for design. Unfortunately, talent for design is more or less something you bring with you, but you can develop it.

Today no one designs by intuition alone. The engineering student, in addition to his ability to design something, must also understand the fundamentals of natural sciences. If he is producing hardware, if he is producing machines, and in doing so works with materials, then he must understand fundamentals of natural sciences. But if he wants to become an executive, if he is interested in sales, interested in administrative problems, he should also understand fundamentals of the social sciences.

A lack of fundamentals in natural sciences has sometimes been rather serious in civil engineering and also in mechanical engineering. The aeronautical engineer has been in a better position, because aeronautical engineering and aeronautical science started almost at the same time, and developed in parallel.

In 1953 the fiftieth anniversary of the first flight occurred. In aeronautical science, Professor Prandtl, who was also Mr. von Karman's teacher in Germany presented the concept of the boundary layer in 1904. And so, almost at the same time as flight became a practical reality, and within ten years started to become an industry, the ideas necessary to understand such things as frictional resistance, stall, separation, and so on—fundamental problems in aeronautical engineering—were developed into a science.

Mr. von Karman recalled the time at which the so-called compressibility effect started to play a role in the airplane design. He was invited to one of the large airplane companies suffering terrible vibrations in the wing, which they believed to be flutter. A look at the records and the design convinced von Karman this had nothing to do with ordinary flutter. The vibrations were caused by shock waves. Later, Schlieren-photography showed the shocks were there. So thermodynamics began to play an important role in aeronautics.

Fortunately, in the early days it was not necessary to learn much of chemistry, for most of the engine companies had chemists who knew about "anti-knock" and that was sufficient. But after the piston engine was replaced by the jet, this method did not work any more, because flow phenomena was related to the chemical process of combustion. The chemical reaction in burning kerosene is something definitely wanted and planned for. But if a missile enters the dense atmosphere, high temperature, dissociation and recombination occur, i.e., you have reactions which you don't want. Nature produces them and you have to understand them.

As space flight and new methods of propulsion develop, it turns out that even chemistry is not enough. We need electromagnetism. Among the many other institutions, Cornell University is one of the centers where this new branch of aerodynamics—what we call "magnetohydrodynamics" is successfully cultivated.

The aeronautical engineer of today must be interested in all neighboring sciences, not only mechanics, thermodynamics, but also chemistry and especially chemical kinetics and electromagnetic theory.

The word "space" created something of a panic in industry and perhaps also in science. Even the Institute of Aeronautical Sciences changed the name to Aero/Space Sciences. However, Mr. von Karman said he did not think aeronautical science is finished now that aero/space science has started. The new science is only an extension of the old one, for the change simply means new ideas on speed limits and new ideas on high altitude.

For some years we'll need airplanes. The problems in airplane design have cropped up in missile design and in the design of any other vehicles. It would be a miracle if vehicles for space could be produced or vehicles for the upper atmosphere without similar problems.

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* Presented before the American Society for Engineering Education, Purdue Univ. Lafayette, Ind.

Shameful waste of capital dollars, poor reliability, inefficient operation, danger to life and property—these are some of the conditions we have observed in far too many industrial power plants. Usually the fault lies in the failure to engage the services of consulting engineers. The authors point out that engineering help for the small industrial plant is available, discuss how it saves dollars and provides better plant and they detail its costs.

By RALPH D. ABERCROMBIE*

and T. EDWARD WALKAMA*

Consulting Engineering for Small Industrial Plants

WHEN the owner or manager of a small industrial plant is planning new plant facilities—a new boiler, for example—his usual approach will be to obtain proposals from a number of boiler companies. Generally the proposal will be based on the same boiler capacity and steam conditions. When he examines the proposals, however, he will find them confusing to compare, even in this day of package boilers. The arguments of the boiler salesmen will confuse him still further. He will probably notice some differences between the proposals but he will not know whether they are significant or not. Nor will he be aware of all the differences and omissions of significant details in the proposals. He will not realize that the cost of installing the various boilers can be widely different. For example, differences can exist in the following areas:

TYPE OF BOILER—fire tube, 2 or 4 pass; water tube; natural or forced circulation

METHOD OF FIRING—natural draft, induced draft, or pressurized firing

FUEL—Type and grade of fuel to be burned: oil, gas or coal

BURNERS—Number and type of burners:

For fuel oil—rotary cup, mechanical atomizing, air or steam atomizing

Ability to maintain steam pressure when cleaning a burner

For gas—ring burner, center fired gun, spud type, intertube, fanmix

For coal—stoker or pulverized firing; type of stoker—chain grate, traveling grate, dump grate, spreader, underfeed, single retort, etc.

DUAL FUEL BURNING EQUIPMENT—oil and gas, oil and coal and gas and coal

FLUE GAS DUCTWORK—required to locate the boiler gas outlet

EXTERNAL PIPING—required due to location of connections on boiler

FAN HORSEPOWER REQUIREMENTS

SPACE—floor space and height required

MAXIMUM STEAMING RATE

THERMAL INSULATION

COSTS—Operating, maintenance, installation

ERECTION SUPERVISION

START-UP—service time included in proposal.

ACCESSORIES—quality and quantity of valves, water, column, instruments, soot blowers, etc.

A consulting engineer can help at this point by thorough evaluation of the proposals. He will be aware of all the differences and he will include in his evaluation the operating cost and the cost of installing each boiler. An evaluation made for a recent project is shown in the accompanying tabulation (Table I). Although Boiler A had the highest delivered and erected price it had the lowest installed cost when all items of cost were considered. In making this evaluation it was necessary to

TABLE I—BOILER BID COMPARISON

	A	B	C	D
1. Manufacturer				
2. Boiler delivered and erected price	$67,500	$64,700	$64,020	$64,980
3. Boiler foundation	2,090	2,980	3,610	3,400
4. Flue gas duct with thermal insulation	400	2,000	6,360	7,400
5. Opening in building wall for soot blower removal	200	800	800	800
6. Extra structural steel support	...	...	500	...
7. Burner operating platform	500	1,000	500	500
8. Miscellaneous piping	900	1,000	800	920
Total Comparative installed cost	$71,590	$72,480	$76,590	$78,000

NOTES—Boiler is an oil-fired water tube package boiler with economizer 45,000 lb per hr capacity, designed for 615 psig, 750 F steam, and 250 F feedwater. (This comparison was taken from an actual project which was completed in 1959.)

*A & W Associates

prepare layouts for each boiler for the purpose of determining all items of cost. In this particular case since the required boiler efficiency was specified and all manufacturers met this specification by including sufficient economizer surface it was not necessary to compare the operating costs of the boilers. In most cases, however, it is necessary also to compare operating costs and boiler performance. Consultants also usually prepare other comparison sheets wherein details of construction, accessories, quality of equipment and other items are compared.

Planning

Even before this point however, the consultant can help in the planning and specification stage. With a good boiler specification many of the above differences will be eliminated. For instance it often happens that the plant manager does not know what boiler capacity he requires. In two instances where consultants were called in after boiler proposals had been received it was found that the boiler sizes as proposed were different from what an engineering study indicated to be desirable. In one case a smaller boiler was found to be adequate. In the other case the plant was happy in obtaining a larger boiler which would take care of future plant expansion. In both of these cases the plant man did not have the time and knowledge required to determine his needs and so in each case he relied on the boiler salesman. Normally the boiler salesman does not have the time and cannot justify taking the time to make the type of study required. In these cases the study made by the consultant involved analyzing steam loads and fuel consumption month by month to determine division between process and space heating loads and also the determination of present and future peak boiler loads. Figure 1 shows the results of one such study. A consultant has the knowledge and experience to make studies like this and invariably they should be carried out.

It is during this period of preliminary design prior to preparing preliminary cost estimates or specifications that the consultant considers such items as the following in his selection of the boiler.

Type of boiler—water tube or fire tube
Type of fuel and fuel burning equipment
Type of load—steady or fluctuating
Desired limits to moisture content of the steam during load changes
Quality of feedwater and water treatment
Type of boiler feed pump
Type of boiler drum level control
Type of combustion control
Deaerating feedwater heater
Type of combustion safeguard controls

Frequently, it is during construction when the plant man considers some of these items, and then it is too late to properly incorporate desirable additions to the design. The owner may now be "over a barrel" as to the extras involved. The consulting engineer can still help at this stage, but he will be handicapped by the commitments made before he entered the picture.

Construction Cost Estimates

After the preliminary design work the consultant will

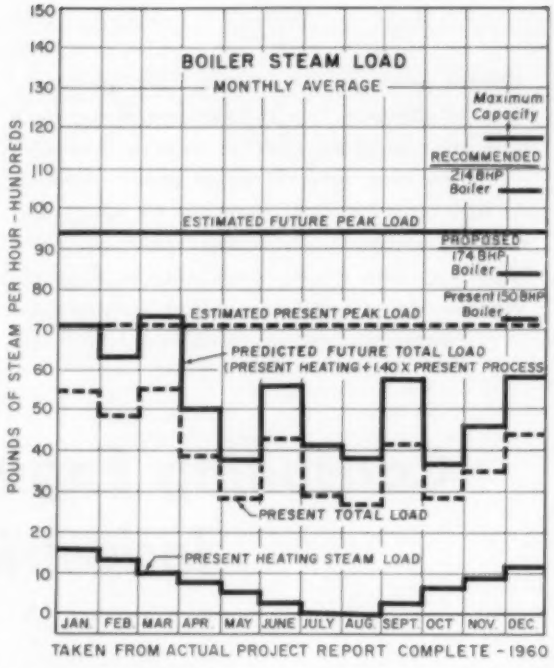


Fig. 1- Monthly analysis of plant process and heating steam requirements

usually prepare construction cost estimates of all the schemes he may have considered. In his estimate he will have included all equipment and details necessary to make a complete project. Many times when a plant purchases a boiler and has the boiler installed by their own forces or by a contractor, details necessary to complete the job are only thought of as the job progresses and sometimes at the last moment. This procedure not only adds to the cost but also delays initial operation.

The construction cost estimates after being prepared are then submitted by the consultant to the client along with the consultant's recommendation in the form of an informal report or, where required, a more formal report. This is the point where the plant owner can decide, based on the estimates, how much money he should budget for the project. It is also a point where, if there is a separate fee for the report the consultant is in a position to inform the client of the amount of his fee for the remainder of the work.

Competitive Bids

In order to produce good, low cost projects it is essential to obtain good competitive bids. Good competitive bids are obtained only when the specifications and drawings are carefully made and when they are complete and clear. Since consultants are dealing with new construction or plant modernization and improvement all the time and are preparing specifications and drawings day in and day out, this is the type of work they can do well. By complete we mean the inclusion of all the small details necessary to insure a satisfactory project. The consultant will also have considered in his design all the types of new equipment, controls and accessories available. As a part of his work he keeps himself informed of new developments by attending technical meetings, reading technical and sales literature, and talking with

salesmen. On a recent small project totaling about $25,000 it is estimated that by the use of specifications and drawings as prepared by a consultant there was a saving of almost $5000 as compared to a previous installation which the plant personnel had handled directly. In this case the savings were not due so much to a lower boiler price which was about $11,000 as in the lower cost of installing the piping and auxiliary equipment necessary for a complete job.

The value of complete drawings was shown on another project where, due to a client's insistence, drawings without full details were sent out for bids. The price received for erecting equipment and connecting piping in a small boiler house was $46,000. Later after full detailed drawings were available the job was rebid and a price of $37,000 obtained from the same contractor. In the first case the contractor had to guess at the details and include a contingency to cover his guesses.

When a plant has purchased a boiler without the benefit of a consultant the usual method is to ask a contractor or a number of contractors what it would cost to complete the boiler installation and make it ready for operation. If the installation is to be properly built the contractor's price must cover the cost of any engineering required. In any case the **engineering cost is included whether covered by the contractor's price or the consultant's fee.** The contractor, even assuming he can do the engineering, will do as little as possible since he is trying to meet a price. It is granted that it is possible in some cases for a contractor to submit a lower price for a project of his design than the price for a project designed and engineered by a consultant. This can be done by arrangement of piping and equipment in a manner which may make for low cost installation but will be so poor as to make maintenance almost impossible and operation difficult. Also, cheaper valves and accessories can be used—less thermal insulation can be installed—essential accessories such as instruments and controls can be omitted. These shortcuts almost invariably lead to higher operating and maintenance costs.

Construction Management

The next phase of a project can be described as construction management. If the plant has awarded the work to one contractor this agent acts as a general contractor and must do the coordination and check shop drawings of all equipment vendors. On the other hand, this type of project may often be handled at a lower cost if the work is split among a number of contractors. In that case the plant manager must do the coordination. When a consultant is engaged he does the coordination and prepares construction schedules.

Supervision and inspection of construction to insure that the work is being installed in conformance with specifications and drawings is another service that consultants provide.

Start-Up Supervision

The final phase of a project is start-up and initial operation, and although it is a very important phase it is too often neglected. As a result many projects, particularly small ones in the area being considered—although they may run—never operate in accordance with the design capabilities and efficiency of the equipment installed. Recently in a plant with a three year old 30,000 lb per hr deaerator it was found that the feedwater temperature was only 200 F and that the boiler tubes were showing evidence of oxygen corrosion. When asked why the temperature was not around 220 F so as to obtain proper deaeration (which would have eliminated the pitting and extended the boiler life), the plant operator said it was operating just as the contractor had left it. Apparently no one had properly adjusted the pressure reducing valve in the steam inlet line.

Coordination of start-up activities is necessary to make certain that all equipment and controls are placed in proper working order. Often if this work is not properly coordinated there are undue delays in placing the project in operation. Supervision of start-up and initial operation is a service that consultants sometimes fail to offer but we think it is a service that must be included. (*Editor's Note*—See COMBUSTION, Nov. 1960, page 55 for a report on similar services on a utility contract.) Contractors and service men generally can place a project in adequate operation but they often fail to obtain optimum performance unless there is a consultant to "ride herd" on them. It is also necessary during this initial operating period that performance be checked to see that equipment performs as designed, specified and guaranteed. This is another service that the consultant provides.

Why Don't Industrial Plants Engage Consultants?

Why then, with all these benefits that accrue from engaging a consultant, don't plant owners and managers engage consultants more often? Sometimes we think it is because they don't want to go to a large firm handling big utility power plants and they don't know where to find a small firm qualified for the work. This is an area where consultants will have to do more educational and promotional work. More often however they feel the consultant's fees can be eliminated, and that they can obtain just as good a job at a lower cost by relying on their own talents or the "free engineering" offered by the equipment vendor or contractor. Yet a project designed by a consultant as seen from the earlier discussion should be—and will be—a better project at a lower cost. The engineering costs are always present, whether in the consultant's fee, or absorbed in the equipment price or contractor's cost. **"Free engineering" is worth only what one is paying for it.** Engineering as furnished by the equipment vendors is not detailed or complete because they cannot afford to take the time required. Usually they can be authorative only on their own equipment rather than a complete project. The vendor's design will not be coordinated with the work of other contractors and he will not provide the most economical design because he has to play safe. This is another reason why a consultant's design will produce a better job at a lower cost. He takes the time to make a design which is better as far as end results are concerned and at the same time he makes the project economical by careful design in sizing, selecting and placing of equipment and piping.

Consulting Engineers Fees

How do consultants charge for their services? Costs

will vary depending upon the project and the consultant. The usual method is to charge a percentage of the construction contract cost, minimum fees ranging from about 10% for projects under $10,000 to 6% for projects around $500,000 all depending on the nature and characteristics of the project. Small projects are best handled on a per diem basis with fees ranging from $75 to $100 or more. Small projects are very often handled on an informal basis with the consultant offering recommendations with perhaps brief specifications and sketches and the plant doing the actual work or contracting for it themselves. Another method of charging fees is by a lump sum fee which we think should be used more and which certainly makes for better relationships between client and consultant as it eliminates one possible source of friction.

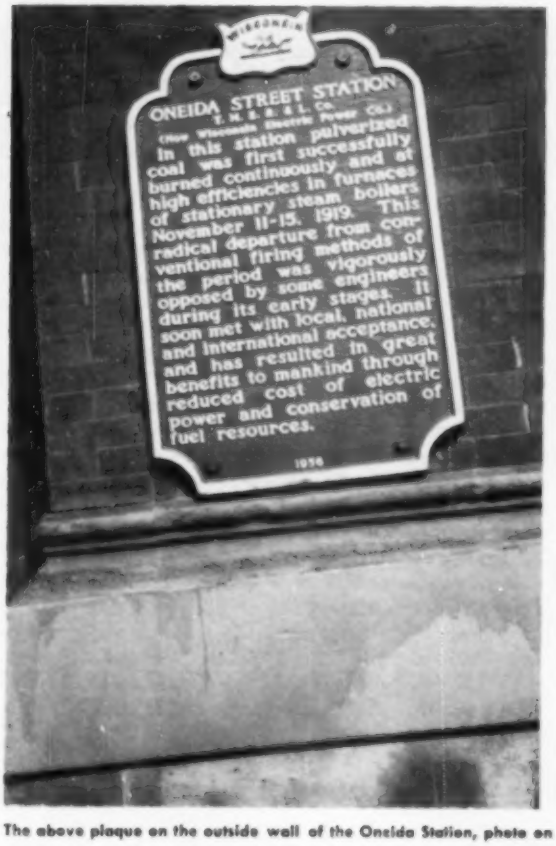
A Salute To Boiler Safety and Progress

A recent mailing from the Uniform Boiler and Pressure Vessel Laws Society reminded us that the safety regulations on boiler construction did not just happen. They were the result of a long drawn out struggle that began to make itself felt with the formation of the first Boiler Code drafted by the ASME in 1914.

Soon afterwards, in 1916 to be exact, the Uniform Boiler and Pressure Vessel Laws Society was formed principally because the ASME Code had not been legally adopted anywhere. As of 1960 all the provinces of Canada except Prince Edward Island, thirty eight of the states of the U.S.A., the District of Columbia, the Panama Canal Zone and Puerto Rico as well as many individual municipalities had adopted one or more sections of the ASME Code.

All of the above was brought home forcibly by receipt of the two photos below, the site of the first pulverized coal-fired stationary steam boiler. We quote from the April 1920 issue of COMBUSTION a summation by John Anderson, then the Chief Engineer for the Milwaukee Electric Railway and Light Co.

"Although frequently cautioned against explosions, we have had no evidence that such caution is necessary. The reason for our freedom from such unpleasant occurrences is due almost entirely to a proper care in preventing coal from being dried too much and pulverized to a fineness beyond what is necessary. Matters of a kind similar to the foregoing are in the hands of the operating engineers and do not benefit by highbrow application of theories. The engineer who is careful of his everyday equipment and keeps his plant free from accidents of every nature, from fly-wheel explosion to burned-out motors, can operate a pulverized fuel plant successfully without other assistance than his own experience."


ONEIDA STREET STATION
In this station pulverized coal was first successfully burned continuously and at high efficiencies in furnaces of stationary steam boilers November 11-15, 1919. This radical departure from conventional firing methods of the period was vigorously opposed by some engineers during its early stages. It soon met with local, national and international acceptance, and has resulted in great benefits to mankind through reduced cost of electric power and conservation of fuel resources.
1956

The above plaque on the outside wall of the Oneida Station, photo on right, of the Milwaukee Electric Railway & Light Co. tells its own story

Eddystone, Philadelphia Electric Boilers Stay Indoors

A basic conclusion that indoor and outdoor boiler plants are comparable in initial costs in the Philadelphia area led the designers of Eddystone to stay with the indoor boiler. Here is the story of the insulation they employed and how it is applied.

By WM. E. SNYDER†

Baldwin-Ehret-Hill, Inc.

EDDYSTONE Station, the new Philadelphia Electric Company unit located southwest of Philadelphia on the banks of the Delaware River near Chester, Pa., is one of the most efficient electric generating stations. Each of the station's two supercritical pressure turbine-generator units has a name plate rating of 325,000 kw. They produce one kilowatt-hour from only 0.62 lb of coal, as opposed to the national average of one kilowatt-hour per 0.93 lb.

As the design of Eddystone progressed, many economic studies were made in an attempt to reduce capital expenditures. One such study concerned boiler design: Indoor or Outdoor? The main advantage of the increasingly popular outdoor boiler is the elimination of a huge building to house the boiler proper. Its main disadvantages are the additional cost of extra insulation and its weatherproofing, plus thermal protection for static flow lines and temporary construction provisions. Outdoor surface insulation is normally $^1/_2$ in. thicker because of lower average ambient temperatures and forced convection caused by wind and, of course, the insulated portions of an outdoor installation have to be weatherproofed, either with sheet metal or mastic at a considerable cost.

In selecting indoor boilers for Eddystone, Philadelphia Electric Company engineers concluded that the initial costs of outdoor and indoor installations are comparable. However, it was felt that to erect a modern curtain wall over existing boiler plant steel in accordance with architectural demands to house the boiler would be less expensive in the long run since maintenance would be reduced. The building itself gives greater protection to the boiler, its accessories and ductwork than if they were erected outdoors and weatherproofed because the indoor boiler does not need a complex weatherproof insulation finish. It need be merely insulated and finished with a single coat of combination insulating-finishing cement.

The results of this economic study are further justified by the fact that the Eddystone Boilers No. 1 and 2 are of the non-drainable type. Any prolonged outage of this type of steam generator under Philadelphia winter conditions would cause high protective maintenance costs.

Design Temperatures

Insulation thickness at Eddystone is based on an average 110 F ambient temperature. This contrasts sharply to the 80 F ambient figure often used. However, the engineers contend that temperatures inside an enclosed power plant are more likely to run in this higher range.

The thermal barrier is designed to achieve an outer surface temperature of 140 F or less in still air. Thus no accessible surface is too hot to touch, and, with only a 20 to 30 degree temperature differential existing between the heated surface and surrounding air, heat loss is minimal.

Insulation Materials

Philadelphia Electric specification for insulation thicknesses on flat and cylindrical surfaces are shown in Table 1. These specifications permit the use of a wide variety of materials.

TABLE I—INSULATION THICKNESS SPECIFICATIONS FOR INDOOR FLAT AND CYLINDRICAL SURFACES

Temperature Range, degrees F	Block Thickness, In.	Finish
Up to 199	1	$^1/_8$-in. thick coat
200 to 299	2	white mineral
300 to 399	$2^1/_2$	wool insulating-
400 to 699	3	finishing cement,
700 to 999	4	reinforced with
1000 to 1099	$4^1/_2$	expanded metal
1100 to 1200	5	lath

Mono-Block, a block felted of spun mineral wool with an inorganic binder, was used as the basic thermal insulation on the No. 1 boiler proper, associated ducts and accessory housings. It was also used on certain parts of the No. 2 boiler.

Coupling a low thermal conductivity with a wide service temperature range, the material is a very efficient

† Field Service Engineer.

Fig. 1—Gas duct from air preheater, showing $^1/_4$-in. tie rods and expanded metal lath reinforcing, is ready for finishing with a single coat of a special cement.

thermal insulator. In addition, it has such desirable mechanical characteristics as high structural strength, light weight, resilience and workability. The photographs illustrate how these characteristics were used to advantage at Eddystone.

On the boiler proper, this felted spun mineral wool block was applied directly to the boiler wall casing, over attachment nuts previously welded to the surface on 12-in. centers. On the sides and bottom of ducts and accessory housings, a steel foundation of 8-gage, 6-in. x 6-in. mesh was tack-welded over existing flanges and stiffeners (Fig. 2). This eliminated the need to build ridges of insulation over these projections and gives a flat finished surface. On the top surfaces of this equipment and on cylindrical surfaces, the block insulation was applied directly to the plate.

Fourteen-gage annealed steel tie wires, secured to either the attachment nuts or steel mesh, were punched through the blocks on 12-in. centers. The blocks were secured by tying the wires to $^1/_4$-in. diameter steel rods, running longitudinally over the blocks (Fig. 1). The rods, spaced on 12-in. centers, secure the blocks.

Fig. 2—Duct work carrying hot air to burners operates at about 600 F. A $1^1/_2$-in. base layer of block is applied over 6- x 6-in. mesh, 8-gage steel foundation, which was tack-welded over the existing flanges. An additional layer of $1^1/_2$-in. block is then applied over the base layer.

Where the two layers of insulation are called for, the block was applied with all joints staggered and both layers secured with tie wires to the external rods.

Voids and joints were pointed with white mineral wool cement. Either expanded metal lath or 1-in. wire mesh was placed over the outer layer of the block insulation to reinforce the finishing cement, a large area of which was a $^3/_8$-in. thick coat of a special white mineral wool insulating-finishing cement, (Fig. 4).

The combination of insulation and cement permitted installation economies since only a single coat of cement was needed. This special cement serves as both an insulating and finishing cement. Keyed into the metal mesh reinforcing and troweled smooth, the cement dried to an attractive glazed white finish (Fig. 5).

Since the expanded metal and the finishing cement do

Fig. 3—Hot air by-pass duct to the right, and gas duct in the foreground are ready for finishing with a single coat of cement. Note use of corner bead to make a clean sharp corner in finished job.

not expand appreciably, irregular cracking could develop at the edges of expanded metal sheets. To control this, the cement was scored so that any cracking resulting from movement or expansion of the hot surface would occur at the score rather than irregularly over the surface. The outer edges of the horizontal and vertical laps of expanded metal were marked and the cement scored at these edges with a jointing tool, so that each score is about $^3/_8$ in. wide and the full depth of the tool.

The only outdoor insulated units at Eddystone are the electric precipitator and the duct between the precipitator and the stack. Here mineral wool block is laid over 6 x 6 in. mesh installed over the duct and precipitator stiffeners leaving an air space between the insulation and the heated surface which provides a slight additional measure of insulation. The finish on these surfaces is a troweling grade water emulsion mastic over 1-in. poultry mesh.

Fig. 4—Super finishing cement is easily troweled over 1-in. wire mesh on this electrical precipitator.

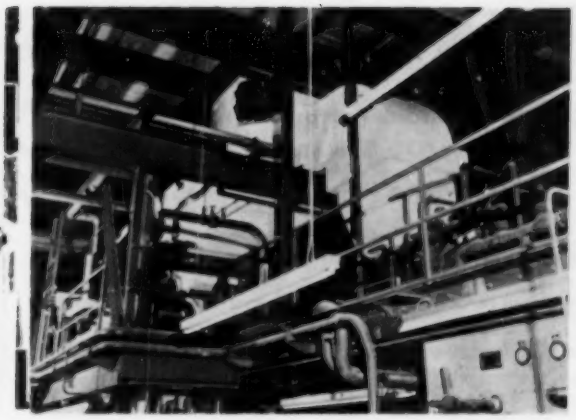


Fig. 5—Smooth, glazed white finish of cement presents an attractive appearance on auxiliary boiler house breeching. A single coat of cement was easily troweled over the block insulation employed. No intermediate bonding surface was required.

Turbine Insulation

An interesting feature of the Eddystone installation is that neither the high or low pressure turbine is cased in metal lagging. Instead, they are merely insulated in accordance with the manufacturer's standard. Unit No. 1 was insulated with Mono-Block in combination with plastic-type mineral wool insulating cement. Unit No. 2 was insulated only with plastic-type mineral wool insulating cement.

There are two reasons for this. One is cost. The housings cost about $40,000 per unit.

The other reason is that maintenance is simpler without the housing. When the turbine is repaired, no heavy bulky metal housing need be removed before the insulation covering the part to be exposed can be torn off. When they are removed, these housings often get so damaged in handling that they must be repaired before they can be fitted back in place. Sometimes they must even be replaced entirely.

In the insulation of either of the units above, one further condition was recognized: none of the materials specified have dusting characteristics which would be objectionable during major turbine maintenance periods.

The Diesel as a Peaking Unit

Fairbanks, Morse & Co., subsidiary of the Fairbanks Whitney Corp., announced it had developed diesel power-generating sets capable of delivering a full load of electric power within 8 to 30 sec after starting from a dead stop, to safeguard cities from blackout when main power sources go dead. The six new engines, the first to have these capabilities (2000 kw each), made up a $1.2 million order to supply stand-by power for the Air Force at Thule radar base in Greenland, 900 miles from the North Pole. The last portion of the order was shipped from Beloit recently.

The six engines can start automatically in case the prime source of power fails. The extraordinary military specifications called on Fairbanks, Morse to construct engines capable of going on full power within 30 sec, but during tests they made it in as short a time as 8 sec.

The Electric Motive Division of General Motors is also very strangely in this field. **Fred Walker**, Manager, Utilities Operations, for that organization presented a very pertinent paper on this subject entitled "Why Decentralized Peak Shaving Equipment" before the Southeastern Electric Exchange in Washington, D. C., Oct. 20, 1960.

Mr. Walker advanced basic cost data, equivalent capacity charges for computing devices, installed transmission and distribution line charges, capitalization problems of immediate interest to his audience. He was subjected to considerable questioning from the floor.

A 1,000,000 Kw Generator?

An engineer of the Westinghouse Electric Corp. has predicted that turbine generators rated at 1,000,000 kw twice as large as any now in use, will be producing power in the United States within the next 15 years. The largest unit in operation in the country today is rated at 475,000 kw.

Clarence J. Baldwin, and electric utility engineer, said Westinghouse has determined that the higher rated units can be economically operated during a two-year study of the problem using a method called "Powercasting.

Powercasting involves the use of computers to simulate detailed operations of a utility in the future. In effect, by programming the future into a computer, utility specialists are able to build a model electric system, in the computer, that will actually operate like a full scale system.

The 1,000,000-kw pattern proved economically superior to one restricted to 500,000-kw units over the next 20 years, he reported. Its economic superiority was unchanged by variations in installed plant cost.

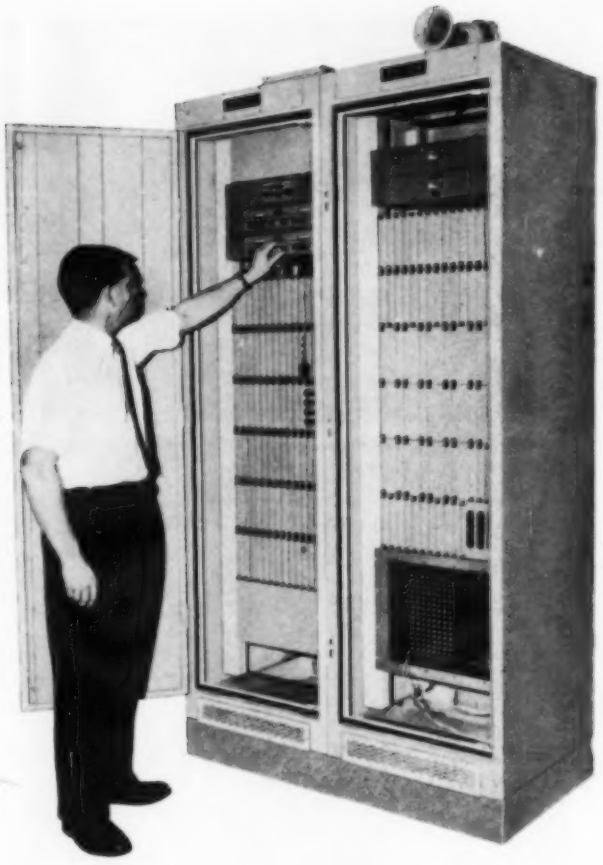
The study showed that patterns using units larger than 1,500,000 kw could be economical were it not for increasing internal transmission costs with the very large units. The 1,500,000-kw units would not be excessively large as far as reserves are concerned. However, the concentration of capacity in one location on some utilities increases transmission costs enough to overcome the economies of the 1,500,000-kw unit.

KEY to functions performed by Bailey 700 Systems

A — Analog **A/D** — Analog and Digital
D — Digital **s** — sense and measure
d — display (indicate, record and/or log)
m — monitor (scan and alarm)
p — produce stored information for future use (tape, cards) **c**—compute **r**—control

● Installed ● On order

LOCATION	TYPE	FUNCTIONS
1. Chelan Co., Wash.	D	sdm
2. Chelan Co., Wash.	D	sd
3. San Francisco	A	sdc
4. Salinas, California	A	sdc
5. Los Angeles	A	sdc
6. Glendale, Ariz.	A	sdc
7. Alameda, N. M.	A	sdc
8. Amarillo, Texas	A/D	sdmc
9. Smithers Lake, Tex.	A	sdr
10. Orange Co., Tex.	A/D	sdmcr
11. Bronte, Tex.	D	sdm
12. Sioux Falls, S. D.	A	sdr
13. Oklahoma City	A	sdc
14. Harrah, Okla.	A	sdc
15. Muskogee, Okla.	A	sdc
16. Lafayette, La.	A	sdc
17. Jackson, Miss.	A	sdc
18. Cleveland, Miss.	A	sdc
19. Memphis, Tenn.	D	sdm
20. Paducah, Ky.	D	sdc
21. Sullivan, Ind.	A	sdc
22. Graham, W. Va.	A	sdc
23. Ashtabula, Ohio	A	sdc
24. Monroe, Mich.	A	sdcr
25. Rochester, N. Y.	A	sdc
26. Ludlowville, N. Y.	D	sdmp
27. Buchanan, N. Y.	A	sdr
28. Fairless Hills, Pa.	D	dm
29. Wilmington, Del.	D	dm
30. Washington, D. C.	D	dp
31. Hamilton Twp., N. J.	A	sdr
32. N. S. Savannah	A	sdr



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G153-2

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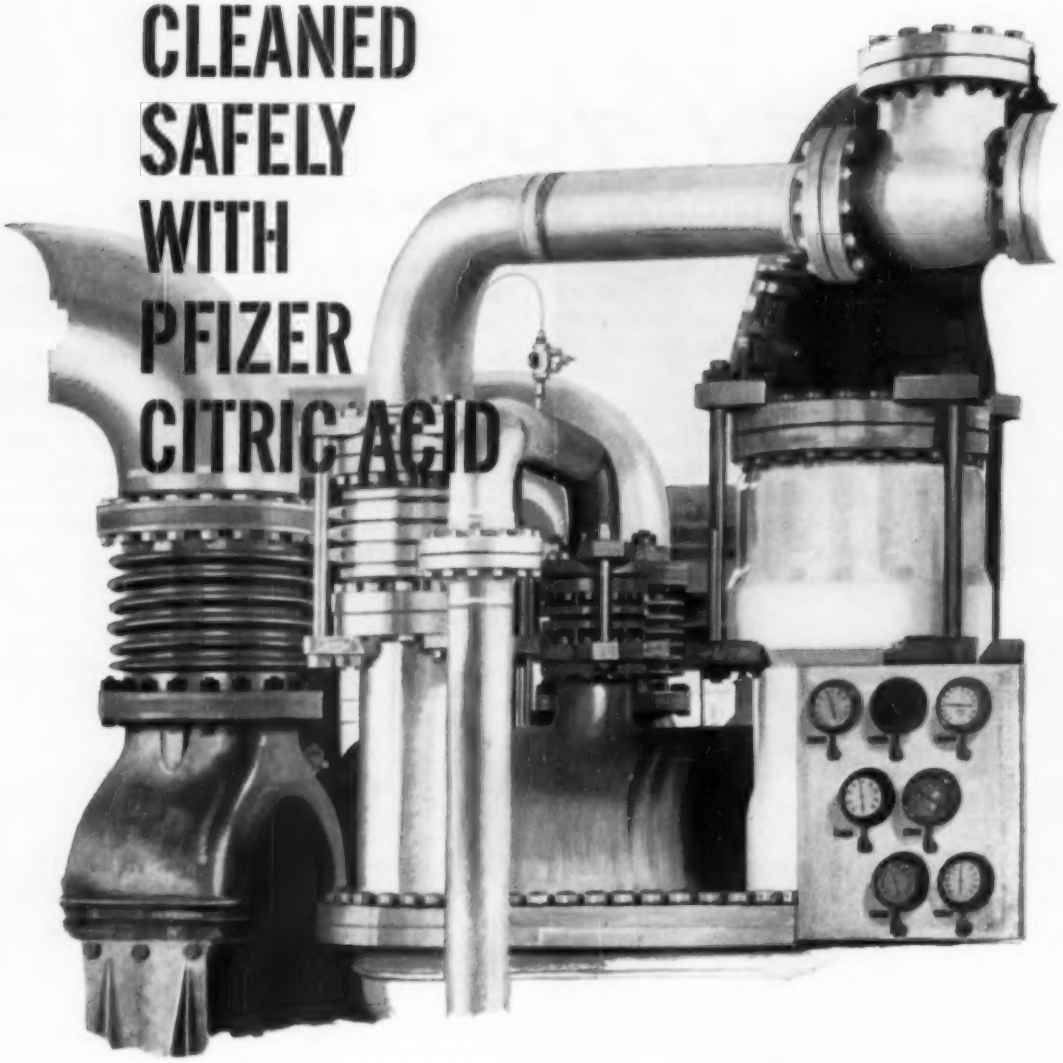

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ASME Annual Meeting Highlights—I

Incoming ASME President W. H. Byrne is congratulated by Philadelphia Electric's J. H. Harlow and Fuels Division Chairman W. T. Reid

THE Statler-Hilton in New York was bursting at the seams early this month with nearly 5000 registrants at the 1960 ASME Annual Meeting. There were 324 technical papers presented in an excellent program and the social events were once again very enjoyable and successful. In our January issue we will present abstracts of still more papers of exceptional interest to the power field.

Solar Energy

J. I. Yellott, Yellott Engineering Assoc., Inc., gave as his paper "Progress Report: Solar Energy in 1960." The successful use of silicon solar batteries on a large scale as power sources for satellite communication systems is 1960's most important contribution to solar-energy utilization. Still far too expensive for any but the most exceptional earthbound applications, the silicon cells which were invented in 1954 and first put into orbit by Vanguard I on March 17, 1958, are standard equipment on the increasingly large and complex vehicles which have been orbited by the United States during 1960. The heavier but less versatile Russian vehicles appear to place more reliance on chemical batteries which are initially powerful but are relatively short-lived.

Primary emphasis continues to be placed on research which will lead to bigger and better satellite power generators. Progress is being made in developing light weight reflectors, radiation-absorbing surfaces with selective wavelength characteristics, and so on, and these components will ultimately be useful in earthbound as well as space applications.

The use of radiation-absorbing roofing materials as solar energy sources for the heat pump is receiving increasing attention in areas where electricity is available at moderate cost and particularly where summer cooling is essential. Where fossil fuels are abundant and cheap, the first cost of solar-energy utilization systems is still too great to enable them to compete with conventional fuel-burning equipment.

Distillation of drinking water from the sea is one application which holds promise of becoming competitive with oil-burning systems in those regions where sunshine is abundant and petroleum is expensive.

In outer space, where clouds and nocturnal darkness do not exist, and where refueling is impossible with today's technology, the sun's unfailing radiation becomes attractive as a power source. For the first time in the long history of solar-energy research, relatively large amounts of government funds are being assigned

to projects which will lead to the building of small but reliable solar-power devices.

The silicon solar cell, which came out of the Bell Telephone Laboratories in 1954 as a by-product of their transistor research, was the twentieth century's first really important break-through in solar-energy technology. Generation of minute but significant quantities of electricity directly from sunshine by photovoltaic cells was well known prior to World War II, but the conversion efficiency of these devices was so small—less than 0.5 per cent—that they were little used except for control and light-measuring purposes. The first Bell silicon cells showed efficiencies of 5 to 7 per cent, and steady development has brought about a twofold improvement in their performance. Licenses under the Bell patents have been granted to a number of manufacturers, and solar batteries are now being produced in large quantities in the United States and Japan.

Most remarkable of the American satellites was Tiros I, which used a battery of 9100 silicon cells to convert sunlight into electricity for its television camera and transmitter. This miniature moon sent back thousands of tape-recorded pictures of the earth and its cloud cover. Their detail was so good that the Weather Bureau has requested a supplementary appropriation to enable these photographs to be analyzed and compared with the meteorological conditions which prevailed when they were being taken.

The largest solar-electric generator which is now on order for a space application will use 50,000 cells mounted on 12 panels to produce 1140 watts. These cells, produced by Hoffman Electronics Corp., will have a guaranteed efficiency of 12 per cent.

At the present time, silicon cells can only be made from single crystals and they are therefore limited in size and very costly. Intensive research is going forward in many laboratories to find ways of increasing the size and reducing the cost of solar batteries. The break-through which will accomplish this remains to be made.

Mr. Yellott treated a number of other developments such as vapor cycles, direct conversion in this detailed fashion. In summation the use of solar energy to generate power on the earth's surface, while attractive in principle, faces almost insuperable economic obstacles at the present time. The predictable dawn-to-dusk and seasonal variations of solar radiation, and the unpredictable interruptions by clouds, leave only a few applications where conventional fuel-burning equipment cannot do a more economical job. Where power is required for pumping irrigation water or running generators, small mass-produced gasoline engines are available at such low prices that solar devices offer no competition. Only in the still-to-be developed tropical areas, where sunlight is plentiful but fuel is expensive and electricity nonexistent, would solar-powered pumps and generators find wide use if they were available.

The next area of general interest in this field "Progress in Space Heating with Solar Energy" was presented by **C. D. Engebretson,** Whirlpool Corp. and MIT, together with **N. G. Ashar,** MIT.

The MIT Solar House IV, they reported, was designed and built to extract part of its space heating and hot-water load from the sun. The house operated successfully during the winter of 1959–60. The total solar incidence on collecting area during the season was 122.4 million Btu, of which 32.4 million Btu was of too low intensity to justify attempted collection. The solar collector operated with an average efficiency of 45 per cent on the residue of 90 million Btu, extracting 40.9 million Btu on the surface of 640 sq ft at 60 deg tilt. The economic operating conditions can be estimated by maximizing the ratio of useful solar-energy collection to the total power cost of collection and heat distribution. For the present design 110 F was found to be the economic optimum storage-tank temperature during winter months. A 46 per cent sharing of the total heat load by the solar system was realized. The solar-heated tank supplied 34.4 million Btu of the total heating load of 74.5 million Btu. The winter at the site of the experiment was more severe than that predicted when the house was originally designed. Also the total solar incidence during the season was lower than normal. Hence a better percentage of the total heating load can be expected to be shared by the solar-heated tank if weather is more favorable.

A. Ralph Yappel, University of Arizona, described "Solar-Energy Steam Generator: Parabolic-Cylinder Mirror Type." In its most recently modified physical state the generator was composed of a mirror, focus type, feedwater drum and the sun-tracking device. Steam was formed within the focus tube itself.

The mirror was of the parabolic-cylinder type, having its axis fixed parallel to a vertical north-south plane at an angle of 32 deg 13 min with the horizontal. The north end of the mirror was elevated above the south end. It was counterbalanced and free to rotate about its axis for 180 deg. The mirror surface was composed of highly reflective, thin, aluminum sheets and had projected area dimensions of 7 by 7 ft. These sheets were very flexible and were fastened to a plastic cradle which was preformed to the parabolic shape. After aiming the mirror manually at the sun before the start of each test, a 1/−150 hp synchronous motor rotated the mirror at 15 deg per hr through a worm and worm wheel. The sun's declination was not accounted for.

Located symmetrically along the mirror focal line was a water-filled, $3^1/_2$-in. O.D., steel tube. The surface of this pipe (focus tube) was coated with lampblack. The sky side of the focus tube was protected by an insulating hood, while 180 deg of the pipe surface on the mirror side was exposed to the air. The hood rotated with the mirror and the focus tube was stationary. A water drum was connected to the south end of the focus tube while the north end was connected to the condenser.

With the mirror aimed directly at the sun, the solar rays incident upon the mirror surface were reflected toward the focus tube. Solar energy was then conducted through the focus-tube wall to the water within the tube. When water vaporization began, the steam bubbled to the north end of the tube and from there passed on to the condenser. The condensate was piped to a weight tank. Steam was bled from the north end of the tube; water entered at the south end. Feedwater flow was manually controlled.

The overall efficiency, 12.6 per cent, is indicative of wind effects when compared to a high of 30.6 per cent, which represents results for the shielded focus tube. A breeze on the day of operation was sufficient to reduce the overall efficiency by over 50 per cent. Naturally, vaporization time was increased and steam produced was decreased considerably when the generator focus tube was unshielded during windy weather.

Calculations for power output were based on the assumption that the steam-generator operation would extend over an average 10-hr day in Tucson. The power equivalent which would be absorbed by the fluid is 8360 kwhr per year, and the cost per kwhr was estimated at 3.5 cents. This amount was established by estimating a combined annual depreciation and maintenance cost of $290. The mass produced cost of the steam generator, including erection, was estimated at $800, which was depreciated over 20 years. This analysis includes performance effects and cost of the steam generator unit only. If a sun-tracking mechanism were included which would account for declination, the estimated average cost per kwhr would be reduced to 3.3 cents. The reduction would result from the greater amount of available solar energy. The steam-generator output cost could be reduced by increasing mirror area. For example: the output cost could be about 2.12 cents per kwhr if the effective mirror surface were doubled. For a quadrupled area, the cost would be about 1.36 cents per kwhr. An analysis to determine the optimum size would necessarily account for aerodynamic stability.

Chemical Cleaning

The rapidly growing field of chemical cleaning not only of boilers proper but of the entire preboiler and boiler systems was thoroughly reported upon in a seven paper session.

Charles M. Loucks, Materials and Methods, Inc., presented the thinking in America on "New Chemical Cleaning Concepts and Possible Applications for the Future." "Let us remember, Mr. Loucks began, that chemical cleaning as applied to plant equipment maintenance is relatively an infant. The often quoted paper by Speller, Chappell, and Russell which describes a "new" method of cleaning a water system, was published in 1927. The foster parents, as you are well aware, were engineers. If the practice has changed little since 1927 or if it has become less than an engineering profession, it is because we have allowed it to become so.

"But what of the future? In general, one may hope that more topnotch technical people will become actively engaged in this specialized field of chemical engineering. Some companies are assigning able engineers and chemists to be specifically concerned with the chemical cleaning aspects of plant maintenance. One hopes that the service contractors will bolster their technical facilities so there can be some competition to see who can come up with the newest and best technical developments. The competition up to now has tended to see who could haul a load of acid cheapest. While that has been good price-wise, it has not motivated technical advances."

The chemical cleaning procedures are, with few exceptions, the same as they were 20 years ago. Mr. Loucks expressed the question "Are you willing to agree that the best that chemical engineering technology can provide is the present cooling off and warming up and worrying about corrosion, the repeated emptying and refilling and inert gas blanketing, the concern about copper leavings, hydrogen in the metal and after rusting?"

Obviously the answer as the author quickly stated is no. Yet what may one hope for even if he doesn't know just how they will come about:

1. Boilers will be cleaned with materials that will allow the boiler to be fired. Much of the cooling down and warming up and filling and emptying and blanketing with inert gas and post boiling can be eliminated.

2. Superheaters, reheaters, steam lines and many piping systems and vessels will be cleaned with noncondensed or vapor phases which offer some very interesting engineering properties.

3. Complete system cleaning with materials other than muriatic acid will allow operating the system facilities without corrosion damage, will reduce downtime and keep efficiency up. Cooling systems will be cleaned without interrupting plant operations.

4. Chemical process and refinery equipment will experience less fouling as more attention is given to the technical aspects of fouling and its prevention. But once fouled, entire systems will be cleaned with organic solvent phases. The solvents will be handled with system facilities, organic and inorganic deposits will be removed. Solvents will be recovered, regenerated, reprocessed, reused or whatever is necessary for economical maintenance.

"Chemical Cleaning of Preboiler Equipment" was the subject presented by **W. B. Willsey,** Philadelphia Electric Co. Cleaning the steam generator alone is doing an incomplete job. The next logical step is to clean the preboiler cycle. It is difficult to evaluate specifically the full effect of reducing the amount of corrosion products entering the boiler during the early operating period. However, it can be shown that continuous addition of these materials to the boiler can result in severe complications and probably boiler-tube failure. Also it is somewhat illogical to spend considerable time and money cleaning these contaminants from the steam generator, only to have them replaced as soon as the heat cycle is put into service.

The other major aspect for preboiler cleaning is silica removal. This is the component that is generally given the most attention and generally thought of as creating the most significant water problem in the preliminary operation of a high pressure steam generator. Silica is generally present in much of the work dirt and general contamination that normally finds its way into equipment during fabrication and erection.

The question arises, how far can or must one go in this precleaning direction? The water side of the heaters and the interconnecting piping of course are generally the easiest part to tackle; however, consideration must also be given to the steam sides of the heaters, bleeder lines, drainer lines, and the hotwell.

Physical complexities such as lines without valves, nondrainable loops, and extremely small surface-to-volume ratios, require special considerations.

The best time to plan for chemical cleaning of the preboiler cycle in the author's opinion is during the design stage, rather than after the equipment has been constructed. If the decision to clean this equipment is arrived at in time to incorporate design features and modifications such as necessary valves and connections appropriately located in the system, and such planning as necessary for heating and flushing of all areas to be chemically cleaned, a more complete and effective job will result.

Usually the feedwater side of the preboiler cycle is the easiest job to tackle, and best lends itself to a cleaning procedure with a minimum of advance preparation. The steam side of the system may be a more difficult arrangement and require considerable preplanning to accomplish a suitable job. However, if it is possible to waste or scavenge all heater drains during preliminary operation, this approach may be used to minimize the contamination of the boiler by the undesirable materials that may arise from the preboiler cycle.

Cleaning the preboiler equipment can be programmed much the same as cleaning a new steam generator. The chief differences from conventional methods of cleaning new steam generators are the utilization of continuous circulation while cleaning, and high-velocity flushing. The basic steps and their functions are:

1. Flushing with water to remove loose and readily soluble material (hot water if available).
2. Alkaline cleaning, similar to boiling out a steam generator to remove work dirt, oily matter, and silica. Concentrations and temperatures would vary with the materials of construction encountered and amount of dirt to be removed.
3. Rinsing in preparation for acid cleaning.
4. Acid cleaning with inhibited acid primarily for oxide removal. The type of acid, inhibitor, concentration, and temperature would again be a function of the materials of construction and contaminants encountered.
5. Rinsing to flush out the acid.
6. Neutralization to insure complete removal of acid. If citric acid is used for cleaning, one may combine the rinse with the neutralization by using ammonia and hydrazine in the rinse without fear of iron precipitation.
7. Passivation, an optional step that should be considered if the system is to remain idle for more than a few days prior to operation.

High-velocity flushing is a very important consideration in planning the job. Techniques should be planned so that velocities are equal to, or greater than, those encountered during full-load operation. The most critical flushing occurs when chemicals are being removed. Paramount, certainly, is the flush following the acid cleaning. At this stage the flushing will determine the final state of cleanness to be obtained.

Circulation of solvents during the cleaning operation is a much argued proposition; however, circulating equipment for the system during the cleaning program offers several advantages. For one, the intricate ups, downs, turns, and complex paths generally found in preboiler cycles do not frequently lend themselves to simple filling, whereas by circulating or flushing at sufficient velocities and venting at the high points, filling can be accomplished. Once the system is filled there is no need for draining if circulation is installed. When adding chemicals, concentrates can be pumped in as the circulation progresses mixing directly in the system. Thus by circulating and flushing as the program requires, the system can be completely cleaned, neutralized, and treated without exposure to air.

The following paper, "Chemical Cleaning of Controlled Circulation Boilers," by **H. J. Vyhnalek,** The Cleveland Electric Illuminating Co., pointed out that controlled-circulation boilers are physically different from their natural-circulation counterparts. They contain small-diameter tubes with flow-controlling orifices; a variety of alloys especially in the pump circuitry and, finally, the circulating pumps themselves. These pumps, while causing some problems in the cleaning process, provide excellent means of solvent circulation.

As a result of modern water technology and condenser design, rarely is a high-pressure unit cleaned to remove raw-water scale. The need rather is dictated by the introduction, production, and deposition of corrosion products, mainly iron, copper, and nickel.

The relative positions of copper and iron (possibly nickel) in the electrochemical series complicate the chemical removal of all materials simultaneously by a single acid stage. Replating of copper on the bare steel is almost certain. However, with the recent introduction of copper complexing agents, which prevent this plating, a single acid stage removal of all materials appears possible. This type of cleaning has the advantages of shortening outage time and removing copper-iron laminar deposits. Consequently, it appears highly desirable to many operators.

There is room here for a note of caution. One must evaluate two important disadvantages: (1) It is only an effective copper remover under very specific conditions, and (2) it increases the corrosion rate of the inhibited hydrochloric acid. Both of these characteristics could make a single-stage cleaning undesirable when copper is present.

The one singular factor which determines the relative life of a boiler tube in a controlled-circulation unit is the condition of its orifice. Deposition in the orifice may seriously hamper proper flow of water to the tube causing subsequent overheating and failure. Orifice deposits may, in many cases, dictate the need for cleaning these units. Therefore, a satisfactory cleaning job cannot be accomplished if this deposition has not been completely removed.

The choice of a single-stage cleaning, in the author's opinion, then depends upon one's knowledge of composition and distribution of the deposits in the circuit being treated. High copper-bearing deposits, such as described, would almost certainly cause in uncertain results using only complexed acid. Under this condition, a two-stage program must be used.

Next month we will publish here more abstracts from the many fine technical papers that were presented at this ASME Annual Meeting.

Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

Reactivity of Coke. K. Hedden. *BrennstChemie* 1960, **41** (July), 193–203 (in German).

The reactivity is determined by passing CO_2 at constant velocity through the furnace in which it reacts with the coke at a temperature kept constant at ±1 C. From the velocity of formation of CO the velocity constant defining the reactivity can be determined. Differences in reactivity of cokes and changes in the reactivity during burning are discussed. In a series of tests the relationship between reactivity and production conditions of the coke could be clarified.

The Transport of Solids in Pipe Lines in Collieries. M. Coeuillet. *Tech. Mod.* 1960, **52** (June), 312–8 (in French).

Examples of hydraulic and pneumatic transport of solids, such as sand, coal and rock, are described and the advantages and disadvantages discussed.

Sampling of "Difficult" Coals: Trials of an Automatic Sampler. A. J. Norman. *J. Inst. Fuel* 1960, **33** (Aug.), 402–5.

The sources of size segregation in loading and unloading coal wagons and the difficulties experienced in obtaining representative samples for ash analyses are discussed. The American sampling device for installation at the tipler is described and results are tabulated. It is concluded that although there may exist a bias in favor of the lower specific-gravity particles in the larger size fractions this sampler is preferred to other methods for taking samples from wagons.

Heat: Cycles and Transmission

Radiant Heat-Transfer Analysis of a Furnace or Other Combustion Enclosure. J. T. Bevans. *ASME Preprint* No. 60-HT-12 1960 (Aug.), 7 pp.

An analysis more complete than that of Lobo and Evans but less difficult and time consuming that that of Hottel or Oppenheim is presented.

Heat Transfer to Water in Turbulent Flow in Internally Heated Annuli. Pt. 1. Stationary Flow; Pt. 2. Pulsating Flow. Z. Rotem and I. Shai. *ASME Preprint* No. 60-HT-20/21 1960 (Aug.), 4 and 5 pp.

The results of experimental investigations of local heat transfer and friction in turbulent stationary and pulsating flow of water through a circular concentric annular duct are presented.

The Effect of Density Variation on Heat Transfer in the Critical Region. Y.-Y. Hsu and J. M. Smith. *ASME Preprint* No. 60-HT-8 1960 (Aug.), 6 pp.

A method has been developed for predicting the influence of density variations on transfer of momentum and heat in the critical region. The results show that in heating the velocity and temperature profiles are flattened and the heat transfer coefficient at a given Reynolds number is increased. Investigations of the effect of natural convection showed that

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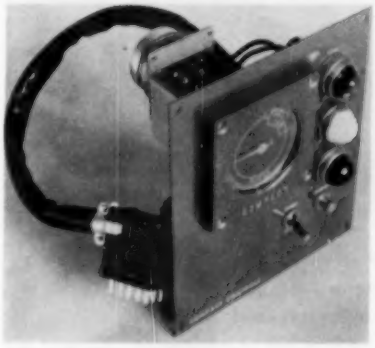

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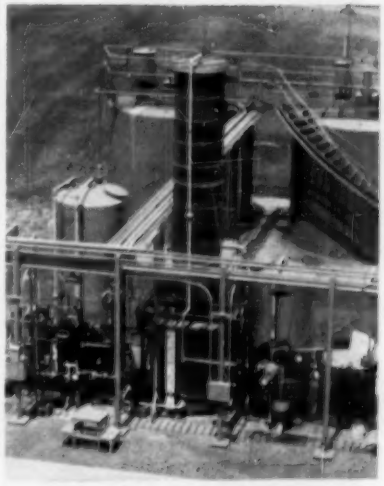

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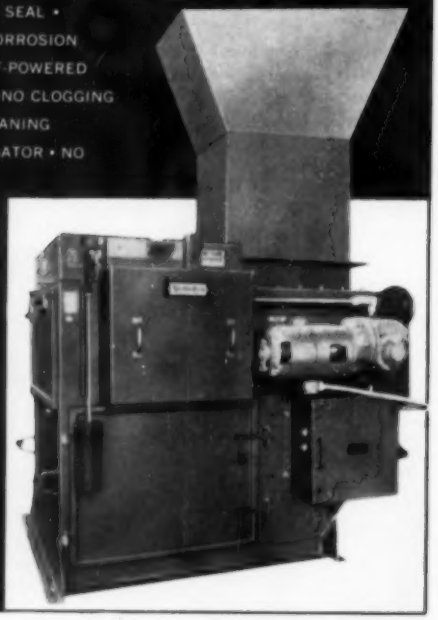

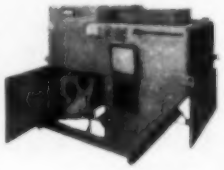

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Steam Generation and Power Production

Determination of the Viscosity of Steam at Supercritical Pressures. E. Ljelland-Fosterud. *J. Mech. Engng. Sci.* 1959, **1** (June), 30–8.

The viscosity of steam has been measured at pressures of 200 to 1000 atü and temperatures of 370 to 540 C. The apparatus used is described and the results are tabulated.

An Equation of State for Liquid Water Valid up to 300 C and 1200 atü. R. Plank. *B.W.K.* 1960, **12** (July), 302–4 (in German).

The new semi-empirical equation has been deduced from the tables for the specific volume of water published by the Moskow Institute of Energy.

Energy Diagrams for Water and Steam. Z. Rant. *B.W.K.* **1960**, **12** (July), 297–301 (in German).

Exergy diagrams show much better than energy diagrams where the losses in the steam power process occur and where the greatest scope for improvements still exists. The new diagrams in combinations with the earlier ones for air and flue gases are used to show the energy and exergy flow in two examples, one a steam generator and the other a power station.

Photo-Elastic Exploration of the Stresses in a Design for a Full-Bore Closure for a Reactor Pressure Vessel. C. Snell and H. T. Jessop. *J. Mech. Engng. Sci.* 1959, **1** (Sept.), 144–50.

The Turbo-Furnace. J. D. Williams. *J. Inst. Fuel* 1960, **33** (July), 328–36.

This boiler was first developed for slag-tap firing of low-grade coal and is characterized by the opposed, downwardly inclined burners in the front and rear wall. Despite the absence of soot blowers the furnace has remained clean. One of the largest built is rated at 1550 klb/h at 1925 psi and 1005 F with a water-cooled furnace floor lined with castable refractory. Other boilers have been designed for gas and oil firing, and one rated at 800 klb/h at 1600 psi and 1005/1005 F for oil firing is to be installed at Bankside "B" power station.

Towards Cheaper Steam. Anon. *Pwr. & Works Engng.* 1960, **55** (July), 499–502.

At the N.C.B.'s Central Engineering Establishment at Bretby a boiler house has been erected to find the best way of burning low-grade coal without smoke emission in shell-type boilers. The fuel used is very dry

$^1/_2$ in. unwashed slack which is conditioned with water on a conveyor belt and delivered to bunkers with a glass-lined bottom; the chutes to the stoker hoppers are also glass-lined to prevent hold-ups. A baffle is installed in the furnace flue behind the bridge to prevent dust accumulation. The induced draught fans have shunt-type scroll vortex grit arrestors with secondary centrifugal collectors to minimize grit emission.

The Packaged Boiler and Its Application. D. F. Brice. *Brit. Pwr. Engng.* 1960, **1** (Aug.), 37–40.

A review of packaged, oil-fired, fire-tube, water-tube and monotube boilers, their ratings and applications.

What it Takes in Piping for a Supercritical Unit. C. A. Dauber. *Pwr. Engng.* 1960, **64** (July), 51–3.

Brief information is given of materials and sizes used for various pipelines and valves at Avon No. 8 unit of the Cleveland Electric Illuminating Company's supercritical monotube boiler at 3500 psi and 1100/1050 F.

Solid Fuel Firing

A.S.A. Standards for Pulverized Fuel Systems. Anon. *Combustion* 1960, **32** (July), 26–36.

A complete reprint of the latest American Standards Association Code Z 12.7—1959 for the installation and operation of pulverized fuel systems. It contains the following chapters: (1) Introduction; (2) General requirements; (3) Installation of pulverized fuel systems; (4) Lighting and operating pulverized fuel systems; (5) Fire prevention and fire protection.

Combustion Research and Fuel Policy; A New Look in Combustion Research. M. W. Thring. *J. Inst. Fuel* 1960, **33** (Aug.), 406–9.

A brief outline is given of the fields in which research into the combustion of coal, oil and gas appears most fruitful.

Flow Patterns in Three-Dimensional Shapes. A Background for Furnace Design. N. P. Bacon, J. H. Chesters and I. M. Halliday. *J. Iron & Steel Inst.* 1960, **195** (July), 286–92.

Studies of flow patterns in cubes, spheres, cones, cylinders and other three-dimensional shapes are described and the behavior of enclosed and free jets compared. Flow in the cube can be taken as the prototype for all furnaces, that in the sphere and hemisphere for gas holders during filling and for ignition hoods, that in the cone for a burner quarl, that in the cylinder for Lancashire boiler, flame tunnels and rotary kilns.

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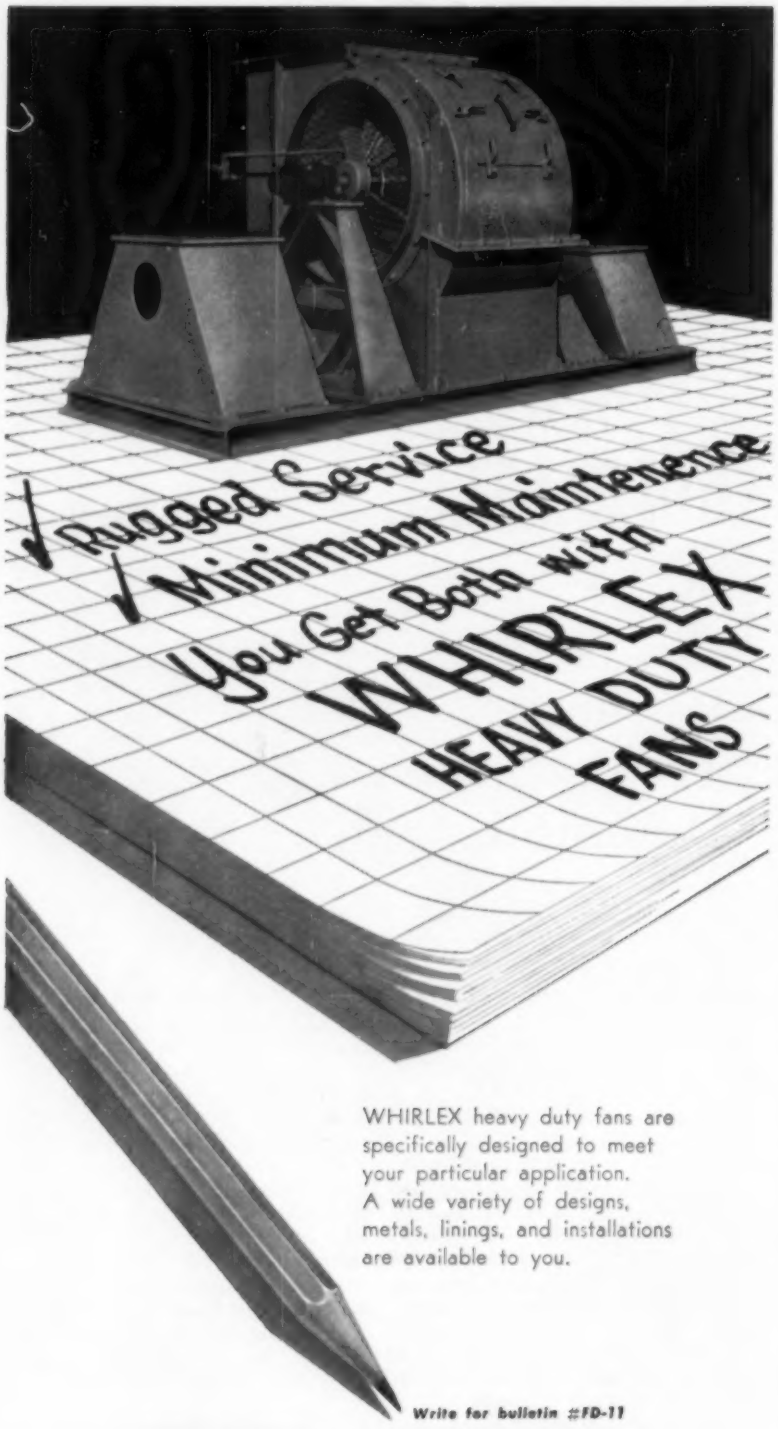

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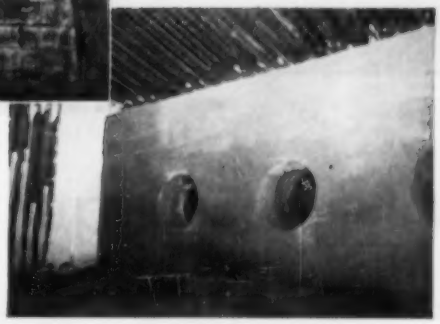
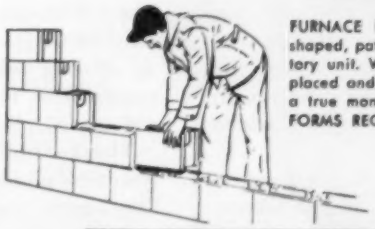


Burner wall, 8 ft. high x 26 ft. wide, of oil-fired boiler showing perfect condition after nine months' service.



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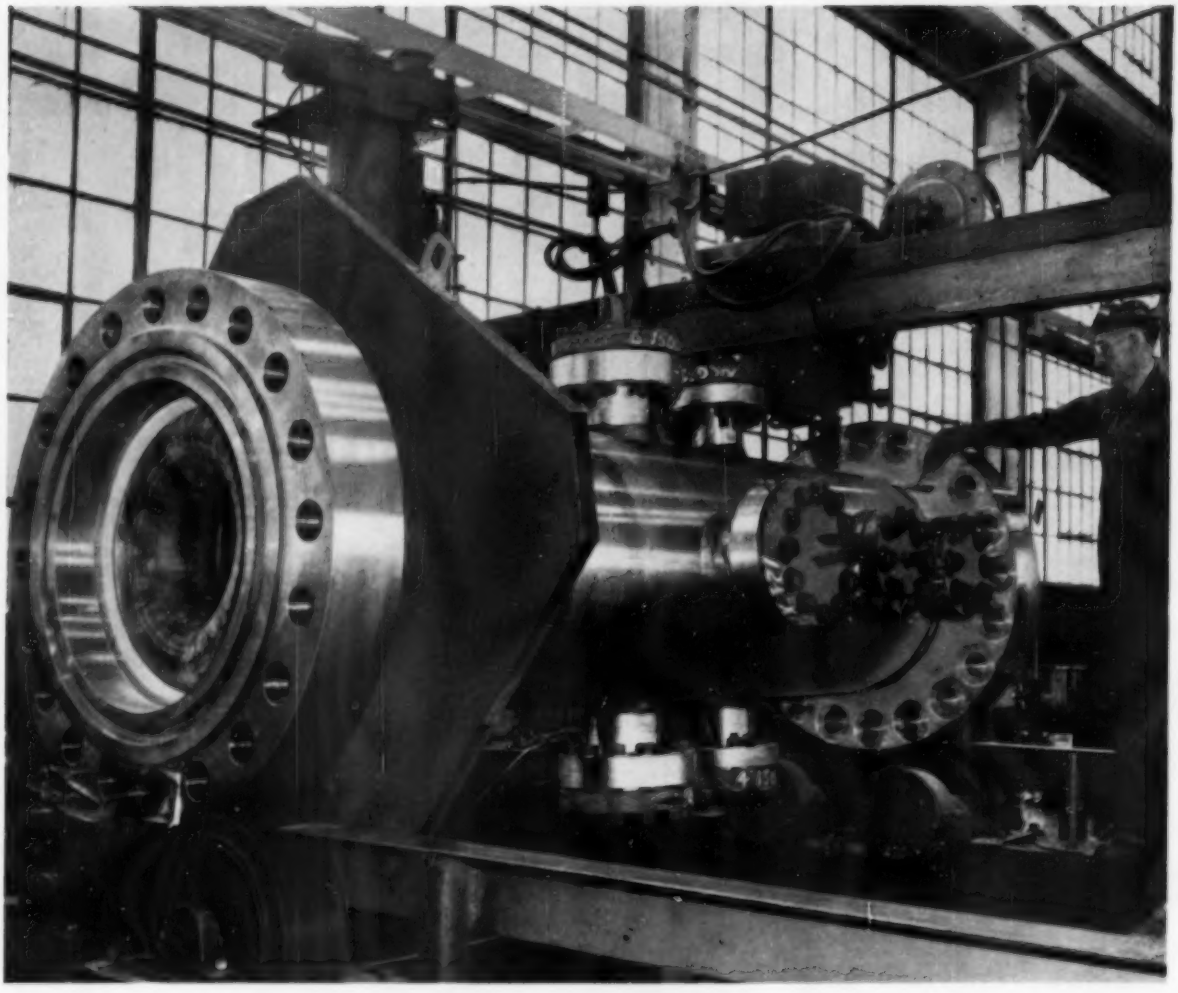

Test vessel fabricated for Westinghouse Electric Corporation.

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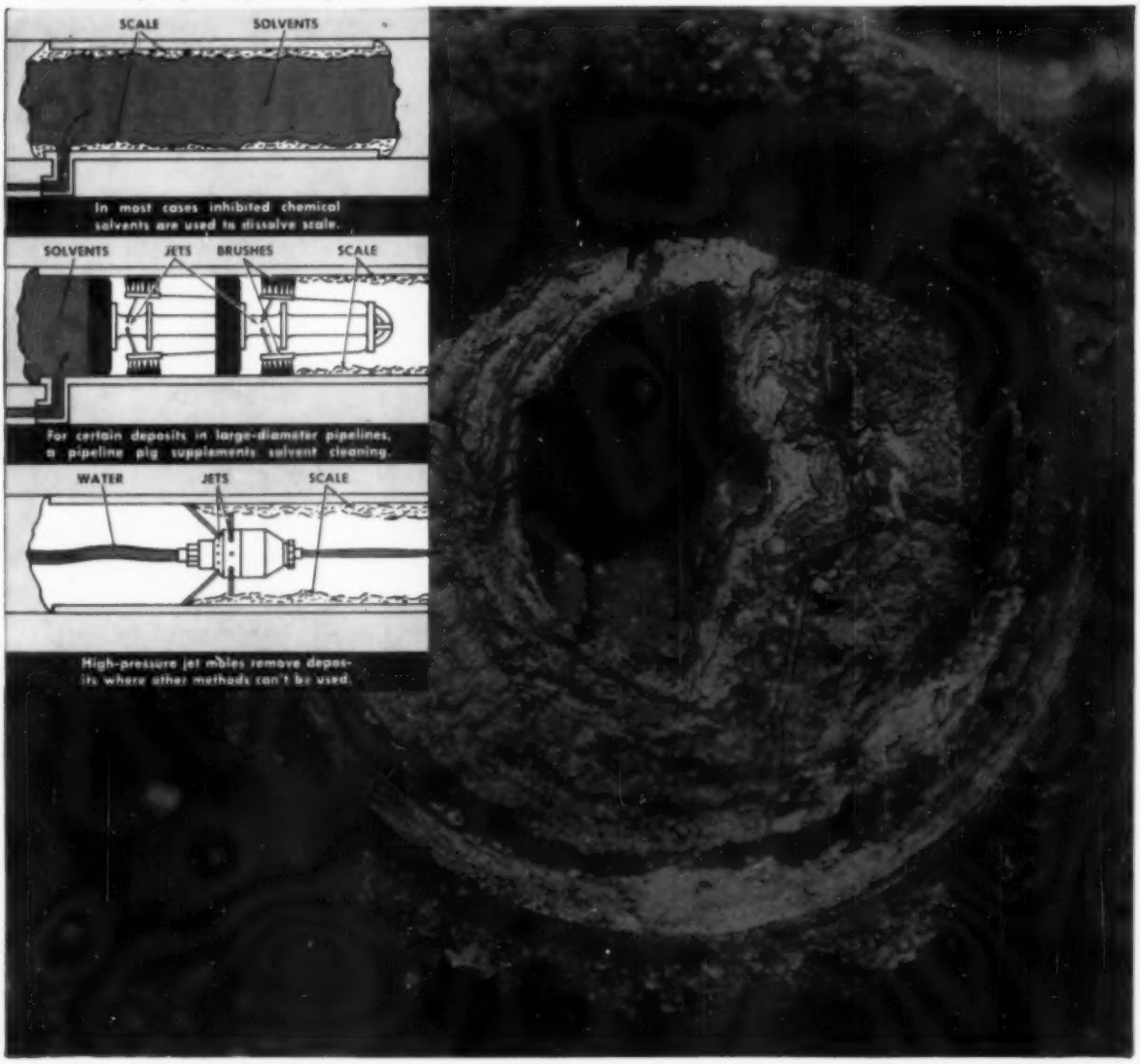
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